Stream Habitat Investigations and Assistance

Federal Aid Project F-161-R18

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Federal Aid in Fish and Wildlife Restoration

Job Progress Report

Colorado Parks & Wildlife

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Fort Collins, Colorado

August 2012

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The results of the research investigations contained in this report represent work of the authors and may or may not have been implemented as Colorado Parks & Wildlife policy by the Director or the Wildlife Commission.

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SEGMENT NARRATIVE

State: Colorado

Project Number: F-161

Project Title: Stream Habitat Investigations and Assistance

Period Covered: July 1, 2011 through June 30, 2012

Principal Investigator: Matt C. Kondratieff

Project Objective: To evaluate fishery response to stream aquatic habitat treatments; to evaluate the barrier potential of instream obstacles; and to provide technical assistance for statewide aquatic habitat improvement projects and fish passage structure and barrier designs.

STUDY PLAN A: DESIGN, CONSTRUCTION AND EVALUATION OF STREAM HABITAT RESTORATION TREATMENTS AND INSTREAM STRUCTURES

Job A.1. Fishery Response to Stream Aquatic Habitat Treatments

Job Objectives: Stream habitat improvements will be evaluated to quantify changes in salmonid biomass (quantity), individual fish size (quality), and fish utilization of habitat treatments in restored versus un-restored river segments. A Before/ After/ Control/ Treatment (BACT) study will be conducted at appropriate site locations. A combination of field and theoretical results from this study will be used to evaluate the fishery response to stream habitat treatments. Research findings will generate information useful for quantifying how much improvement in the fishery can be expected from stream restoration projects. Results from this study will refine stream aquatic habitat restoration techniques that will benefit anglers and improve trout fisheries.

Segment Objective 1: Develop list of candidate stream segments to conduct pre- and post- stream habitat improvement studies. Select appropriate study site location(s) for evaluation.

ACCOMPLISHMENTS

A list of candidate stream segments for conducting BACT studies of fish response to selected treatments was completed during the previous reporting period under Federal Aid Project F-161-R17 (Table 1).

Candidate sites for our BACT monitoring study must have the following characteristics: fish populations have stabilized post-whirling disease infection, multiple years (at least 2) of baseline fish data have been collected prior to stream restoration, Colorado Parks and Wildlife (CPW) leases or owns stream public fishing access, proposed restoration sites have been identified, prioritized and funded allowing adequate time to collect good "before" data prior to construction and CPW personnel will be able to work closely with contractors on design and implementation of habitat treatments (design build). Some sites that were considered exceptions because they did not fit all of the criteria listed above but were still deemed valuable to include in our list of long-term BACT monitoring sites were the following:

<u>Middle Fork of South Platte River: Badger Basin:</u> Construction on the Middle Fork of the South Platte River project (Table 1) began prior to collecting "before" fish data for this site. However, a control reach located within 1.0 mile downstream of the project site has been monitored for 19 years and serves as a good spatial control site that is representative of the condition of the Middle Fork project reach prior to implementing habitat enhancement treatments. Pairing the Middle Fork project with the downstream control reach should allow for a direct comparison of fish population statistics.

<u>Tarryall Creek:</u> The Tarryall Project and Phase 1 and 2 of the South Platte River (downstream of Spinney Mountain Reservoir) were both constructed prior to any control reach being established. However, they both include good "before" data for the treatment reach so we included them in Table 1 as locations we plan to continue monitoring over time.

Study sites include a variety of spatial scales including smaller headwater streams with bankfull widths less than 20 feet (i.e. South Fork of South Platte River) up to large rivers with bankfull widths over 100 feet wide (i.e. Rio Grande River).

Table 1. Proposed stream segments to conduct pre- and post- stream habitat improvement studies.

Stream	Construction Years	Project Status	Length (mile)	Primary Treatments	Treatment Reach: No. Years fish data collected "Before" work started / No. Years fish data collected "After" work completed	Control Reach: No. Years fish data collected "Before" work started / No. Years fish data collected "After" work completed	Project Description
Rio Grande River	2006	Completed	4.4	Reduce channel width, excavate pools, enhance trout habitat	8/5	0/3	Wason and La Garita Ranches
Upper Arkansas River	2011-???	Future project	3.0	Reduce channel width, excavate pools, enhance trout habitat	16/0	16/0	Upper Arkansas NRD project at Hayden Flats
South Platte River: Buckley Ranch	1991	Completed	0.4	Reduce channel width, excavate pools, enhance trout habitat	2/21	2 /21	Upper Spinney SWA/Lower end of Badger Basin perpetual easement
Middle Fork of South Platte River: Badger Basin	2007-2011	Completed	2.0	Reduce channel width, excavate pools, enhance trout habitat	0/2	2/20	Upper Spinney SWA/Lower end of Badger Basin perpetual easement
South Fork of South Platte River	Delayed	Future project	1.0	Reduce channel width, excavate pools, enhance trout habitat	2/0	2/0	River reach upstream of Badger Basin HQ - Lower end of Badger Basin perpetual easement
South Platte River-Phase 1 & 2	1993 & 1998	Completed	0.6	Reduce channel width, increase adult fish cover (vegetative cover and deep pools), stabilize eroding banks and improve instream habitat complexity.	1/8	No control reach	South Platte River downstream of Spinney Reservoir
South Platte River-Phase 5	2013-2015	Future project	1.5	Reduce channel width, excavate pools, enhance trout habitat	0/0	0/0	Lower Spinney SWA (Dream Stream)
South Platte River	2015-2017	Future project	1.0	Reduce channel width, excavate pools , enhance trout habitat	0/0	0/0	River segment downstream of Park Co. Rd 59
Tarryall Creek	2005	Completed	0.6	Increase trout biomass and number of quality-sized (> 14" TL) trout, stabilize eroding banks, reduce channel width, increase habitat complexity	2/2	No control reach	Tarryall Creek on Tarryall SWA
Hartsel Townsite	Delayed	Future project	0.6	Reduce channel width, excavate pools, enhance trout habitat	2/0	2/0	Hartsel Townsite between Highway 24 and Highway 9

Segment Objective 2: Research potential theoretical modeling techniques for evaluating stream restoration treatments (PHABSIM, River 2D, MDSWIMS, IBMs) to determine what will function best to model changes in fish population response related to stream habitat manipulations.

ACCOMPLISHMENTS

No progress on this research question was made during this segment period. CPW recently hired another individual with habitat and hydraulic modeling skills who will assist us with using PHABSIM to model habitat conditions to serve as baseline conditions on a portion of the Upper Arkansas River by segment period ending in 2013. We plan to be able to devote more time and energy to this topic during the next segment period.

Although we have not applied various theoretical modeling techniques to evaluating habitat restoration or enhancement projects specifically, we are experimenting with various theoretical modeling techniques for evaluating fish passage and fish habitat quality at White Water Parks (WWPs).

CPW is currently working with a graduate student from Colorado State University (CSU) to evaluate habitat and hydraulic conditions at various WWPs in Colorado. We are using various 1-dimensional hydraulic models (such as Fish Xing or HEC-RAS) to reproduce hydraulic conditions that are actually occurring at WWP structures. In addition to using 1-dimensional hydraulic models, we plan to evaluate the performance of 2-dimensional (River 2D) and 3-dimensional models as well. This information will be used to evaluate the effectiveness of various models in explain the variation in upstream movement by fish species and life stage. Ultimately, we intend to use the best performing hydraulic model in combination with published fish swimming data to use as a tool for accurately predicting when fish movement around various obstacles (such as WWP structures) is possible.

The methods and techniques used to derive theoretical models applied to studying fish passage and habitat quality at WWPs should be transferable to studies evaluating habitat restoration and enhancement projects in the future.

Segment Objective 3: During summer and fall months, conduct electrofishing sampling to determine salmonid biomass, densities and individual fish lengths in control and treatment study sites to serve as baseline for later comparison.

ACCOMPLISHMENTS

We collected fish sampling data on selected pre- and post-treatment stream reaches to monitor fish response to aquatic treatments with assistance from area aquatic biologists and research scientists. Fish sampling was conducted at the following three study locations:

Rio Grande River: We collected fish sampling data on treated sections of the Rio Grande River on Wason Ranch (3.8 miles) and untreated portions of the Rio Grande River on La Garita Ranch (2.4 miles) by electrofishing with two rafts equipped with throw electrodes. Data collected included fish population estimate data, fish size by relative abundance data, age and growth (scales), and fish species composition data. Four years of fish data have been collected on the Wason Ranch since Dave Rosgen completed work in 2006.

Data was collected October 17-21, 2011. A preliminary report was generated this spring for circulation to interested landowners and project managers. We plan to continue monitoring this site for a minimum of two more years prior to concluding the study and publishing results based on previous studies suggesting five to six years required for fisheries to stabilize post-restoration activities. This study has unique value since it is being conducted on a large river system (most published habitat restoration evaluations are conducted on much smaller streams). See Appendix A for a preliminary report of findings from this study.

A monitoring study was initiated to determine if river enhancement activities (particular treatments) negatively influenced abundance of giant stonefly *Pteronarcys californica* on a reach-wide scale during summer 2011. The giant stonefly likely serves as an important food source for resident trout. Stonefly exuviae were collected and counted in 15 different 100-foot stations above (controls), within (treatment sections), and below (controls) the Wason Ranch study area (Table 2, Figure 1 & 2). We used removal methods to estimate relative abundance of *Pteronarcys californica* across five different reaches (Figure 3). We plan to repeat this monitoring study again in spring 2013 to gather additional evidence for whether or not river enhancement activities negatively influenced *Pteronarcys californica* abundance.

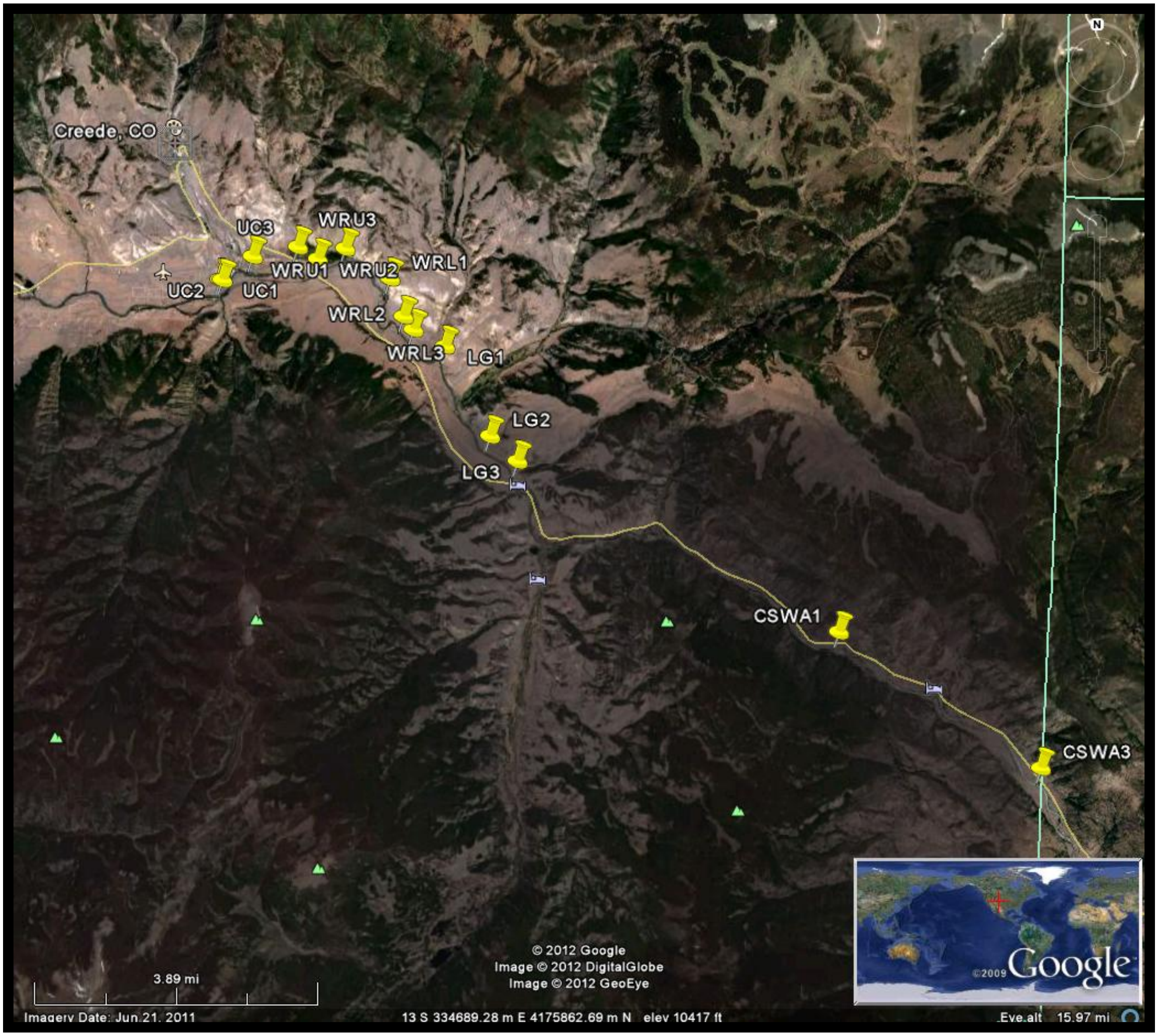

Figure 1. Aerial imagery map showing locations of 15 separate *Pteronarcys californica* monitoring sites used to estimate relative abundance on the Rio Grande River near Creede, CO. UC (Upper Control) serves as an upstream control reach (un-treated habitat), WRU (Wason Ranch Upper) has intensive levels of stream habitat enhancement, WRL (Wason Ranch Lower) has moderate to low levels of stream habitat enhancement work, LG (La Garita Ranch) and CSWA (Coller State Wildlife Area) serve as a downstream control reaches (un-treated habitat).

Table 2. *Pteronarcys californica* monitoring results for 15 separate sites using removal methods to estimate relative abundance. Results include reach location, station I.D., site classification (treatment or control), abundance (exuviae/100 ft station ± 95% C.I.), reach-wide average exuviae abundance (reach average ± SE) and downstream station location (UTMs NAD83).

Location	I.D.	Site Classification	Abundance estimate	Reach Average	UTM X	UTM Y
Upper Control	UC1	Control: upper bound	1,822 (1,811-1,840) p=0.87	951 (±441)	331362	4187243
	UC2	Control: upper bound	638 (635-645) p=0.93		331416	4187238
	UC3	Control: upper bound	394 (391-403) p=0.89		332145	4187768
Wason Upper	WRU1	Treatment: high	433 (425-448) p=0.82	316 (±62)	333211	4187973
	WRU2	Treatment: high	293 (298-318) p=0.81		333668	4187683
	WRU3	Treatment: high	222 (212-245) p=0.72		334313	4187925
Wason Lower	WRL1	Treatment: low	782 (778-792) p=0.78	557 (±224)	335353	4187197
	WRL2	Treatment: low	109 (104-124) p=0.59		335653	4186302
	WRL3	Treatment: low	780 (769-798) p=0.68		335881	4185991
La Garita	LG1	Control: lower bound	277 (275-285) p=0.89	1100 (±596)	336614	4185583
	LG2	Control: lower bound	2,258 (2,251-2,269) p=0.81		337636	4183459
	LG3	Control: lower bound	764 (751-786) p=0.64		338269	4182856
Coller SWA	CSWA1	Control: lower bound	723 (721-727) p=0.87	595 (±64)	345780	4178690
	CSWA2	Control: lower bound	522 (511-541) p=0.79		-	-
	CSWA3	Control: lower bound	541 (535-554) p=0.72		350500	4175385

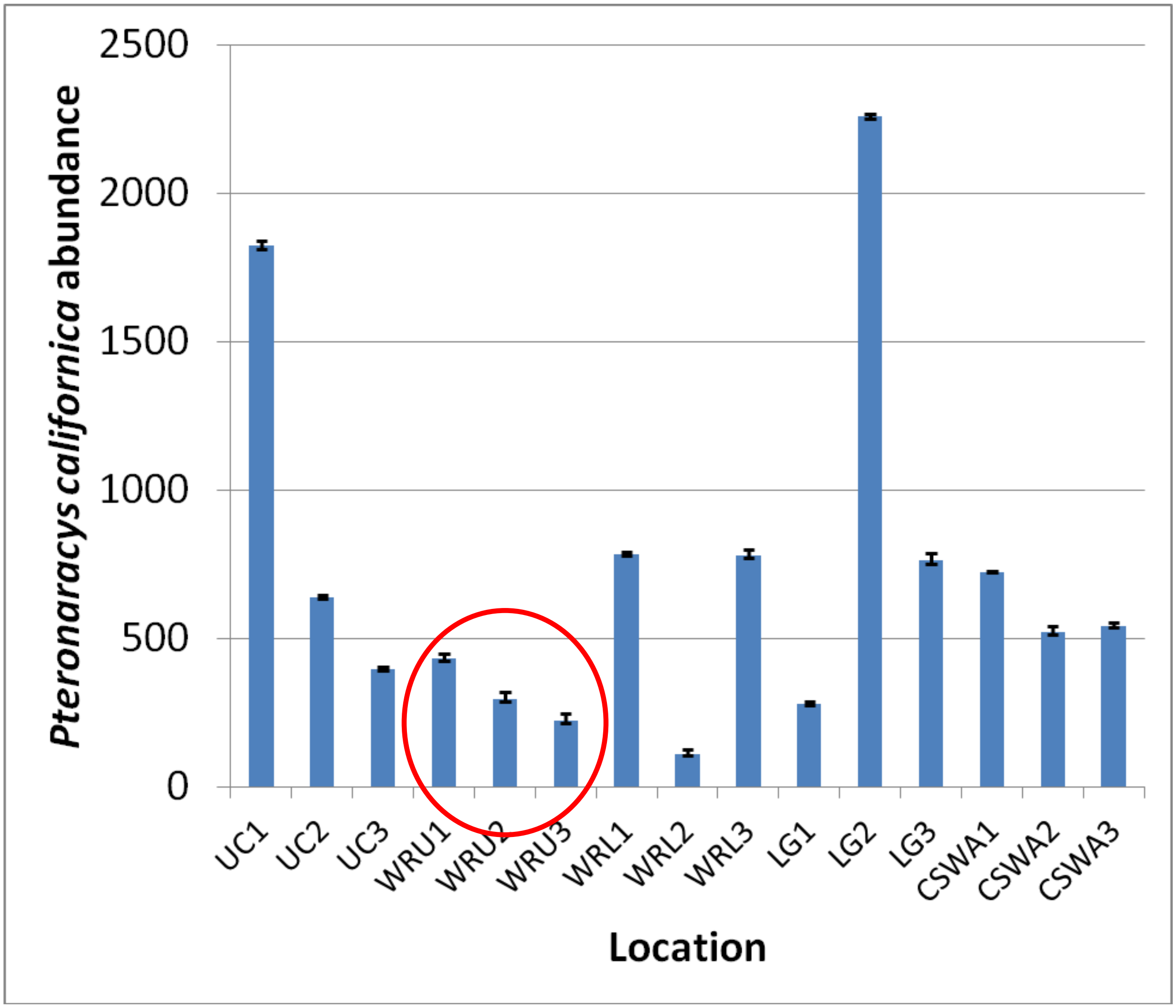

Figure 2. *Pteronarcys californica* monitoring results for 15 separate sites using removal methods to estimate relative abundance. Results include sampling location (x-axis) and relative abundance (exuviae/100 ft station ± 95% C.I.). Red circle indicates stations within the Upper Wason Ranch that experienced the highest level of intensive habitat enhancement (development of deep pools and channel-spanning boulder structures).

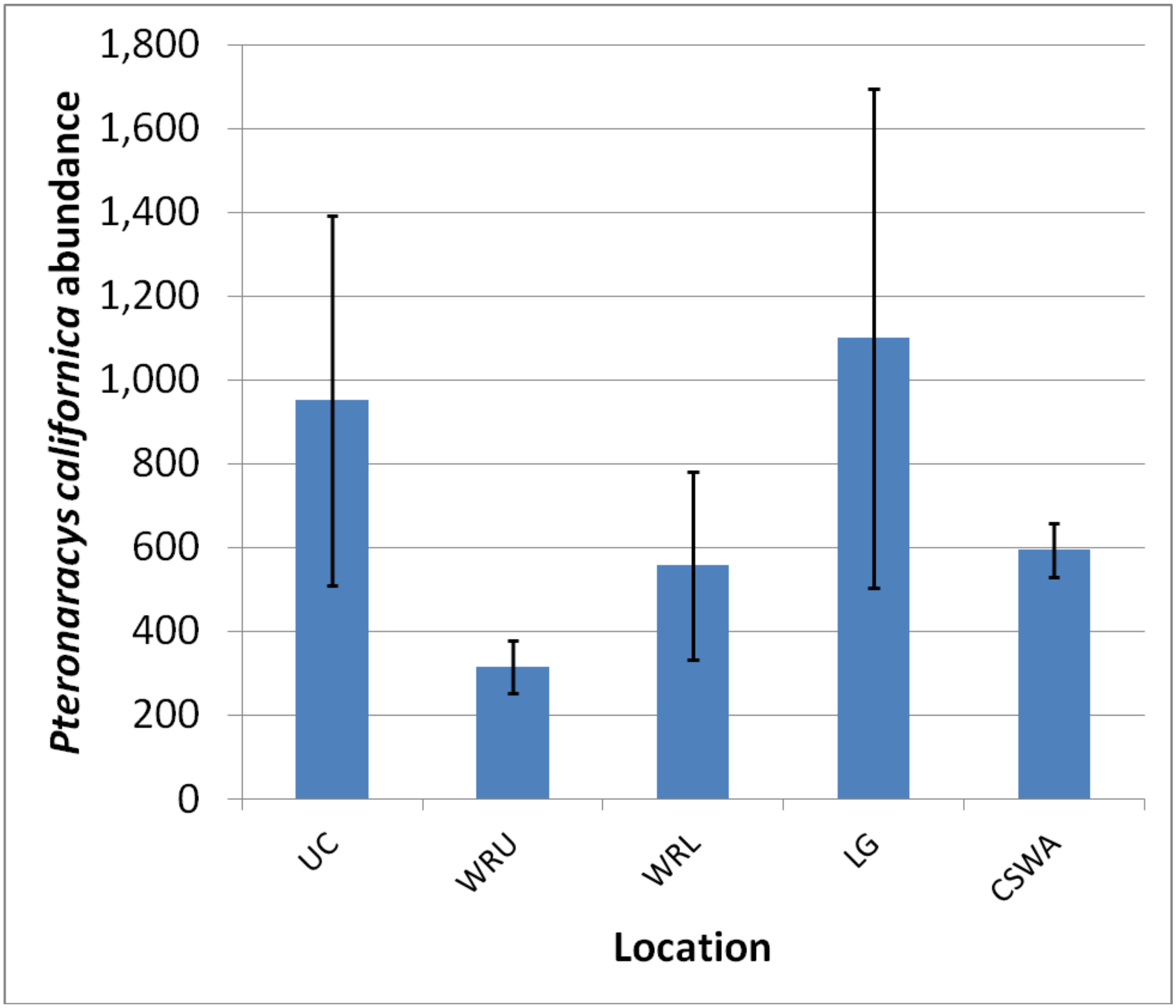

Figure 3. *Pteronarcys californica* monitoring results across 5 separate reaches using removal methods to estimate relative abundance. Results include reach-wide average exuviae abundance (reach average ± SE) pooled across three separate sampling stations on the y-axis and reach location (x-axis). UC (Upper Control) serves as an upstream control reach (un-treated habitat), WRU (Wason Ranch Upper) has intensive levels of stream habitat enhancement, WRL (Wason Ranch Lower) has moderate to low levels of stream habitat enhancement work, LG (La Garita Ranch) and CSWA (Coller State Wildlife Area) serve as a downstream control reaches (un-treated habitat).

South Platte River:

Charlie Meyer SWA: Data was not collected this fall (2011) on the Charlie Meyer SWA "control" and "treatment" reaches due to scheduling/time conflicts associated with recent Parks/Division of Wildlife merger (Jeff Spohn, aquatic biologist was not available to assist during fall 2011). Construction plans were originally intended for this stream segment for the fall of 2012. However, the project and funding was delayed for this year. If the project continues to move forward by next year, fish sampling will be conducted on one treatment and one control site during fall 2012. Two stream electrofishing reaches will be sampled. Sampling sites are located in reaches that are scheduled for future stream restoration work (final phase of Charlie Meyer SWA/ Dream Stream [approximately 2.0 miles] located above Elevenmile Canyon Reservoir). Data collected will include fish population estimate data, length/frequency data, and fish species composition.

Buckley Ranch:

Historic monitoring sites: Data was not collected this fall (2011) on the Buckley "control" and "treatment" reaches due to scheduling/time conflicts associated with recent Parks/Division of Wildlife merger (Jeff Spohn, aquatic biologist was not available to assist during fall 2011). We attempted to sample the Buckley "control" and "treatment" reaches on October 28th, but ice formation due to unseasonably cold overnight temperatures prevented sampling. We will attempt to collect this data again in fall 2012. However, data was collected from the Buckley treatment and control sites during spring (April 16, 2011). Fish sampling has been conducted nearly continuously since the fall of 1990 for these sites. Data collected included fish population estimate data, fish size by relative abundance data, and fish species composition. As of this fall (2012), we will have 21 years of fish monitoring data collected for both the treatment and control sites including two years of pre-restoration baseline fisheries data. The treated reach has consistently had two-three times higher biomass than the control reach since construction was completed in Fall 1991 (Table 3, Figure 4).

Toe-wood sod mat site: In addition to sampling the traditional Buckley Ranch sampling sites (see previous paragraph), a new electrofishing site was established to measure fisheries response due to recent habitat improvements within the Badger Basin SWA project completed during the fall of 2010. In particular the toe-wood sod mat treatment (approximately 200 linear feet of wood-toe treated banks of the 1000 foot electrofishing station) are being evaluated. Fisheries response data was collected from this new reach during the fall and spring of 2011. This information will be compared with data collected from the control and treatment reaches from the Buckley located just 0.15 miles downstream from the Badger Basin project boundary and with upstream reference reach sites to monitor the effectiveness of this new treatment technique (Table 3, Figure 4).

Reference reach sites: We collected fish sampling data on Middle Fork of South Platte River on the Tomahawk SWA during the fall and spring of 2011. Data had been collected as part of a study completed by George Schisler (2002-2004) but no data had been collected since. Fish biomass and density data collected from this site and one site upstream will serve as a "reference reach" and help us set target levels for expected fisheries response for treated (or restored) locations downstream. Detailed habitat surveys from these locations along with fisheries data serve as reference conditions for impaired sites within the South Platte river basin (Table 3).

Table 3. Buckley Ranch Project brown trout biomass (lbs/acre) (± 95% C.I.) results for control, boulder treatment, wood-toe treatment and reference reaches pre-and post-project.

Year	Biomass (lbs/acre)			
	Boulder treatment	Toe-wood treatment	Control	Reference
1990	29 (±5)	N/A	69 (±4)	N/A
1991	44 (±9)	N/A	37 (±5)	N/A
	STREAM RESTORATION			
1992	40 (±3)	N/A	16 (±2)	N/A
1993	50 (±3)	N/A	11 (±1)	N/A
1994	103 (±39)	N/A	18 (±1)	N/A
1995	33 (±2)	N/A	30 (±5)	N/A
1996	66 (±5)	N/A	52 (±2)	N/A
2000	87 (±3)	N/A	35 (±1)	N/A
2002	N/A	N/A	N/A	130 (±16)
2003	51 (±4)	N/A	27 (±1)	215 (±10)
2004	49 (±3)	N/A	10 (±2)	289 (±3)
2007	N/A	N/A	N/A	484 (±6)
2009	41 (±4)	N/A	13 (±2)	204 (±7)
2010	58 (±7)	83 (±10)	24 (±2)	121 (±3)
2011	N/A	52 (±2)	N/A	95 (±2)

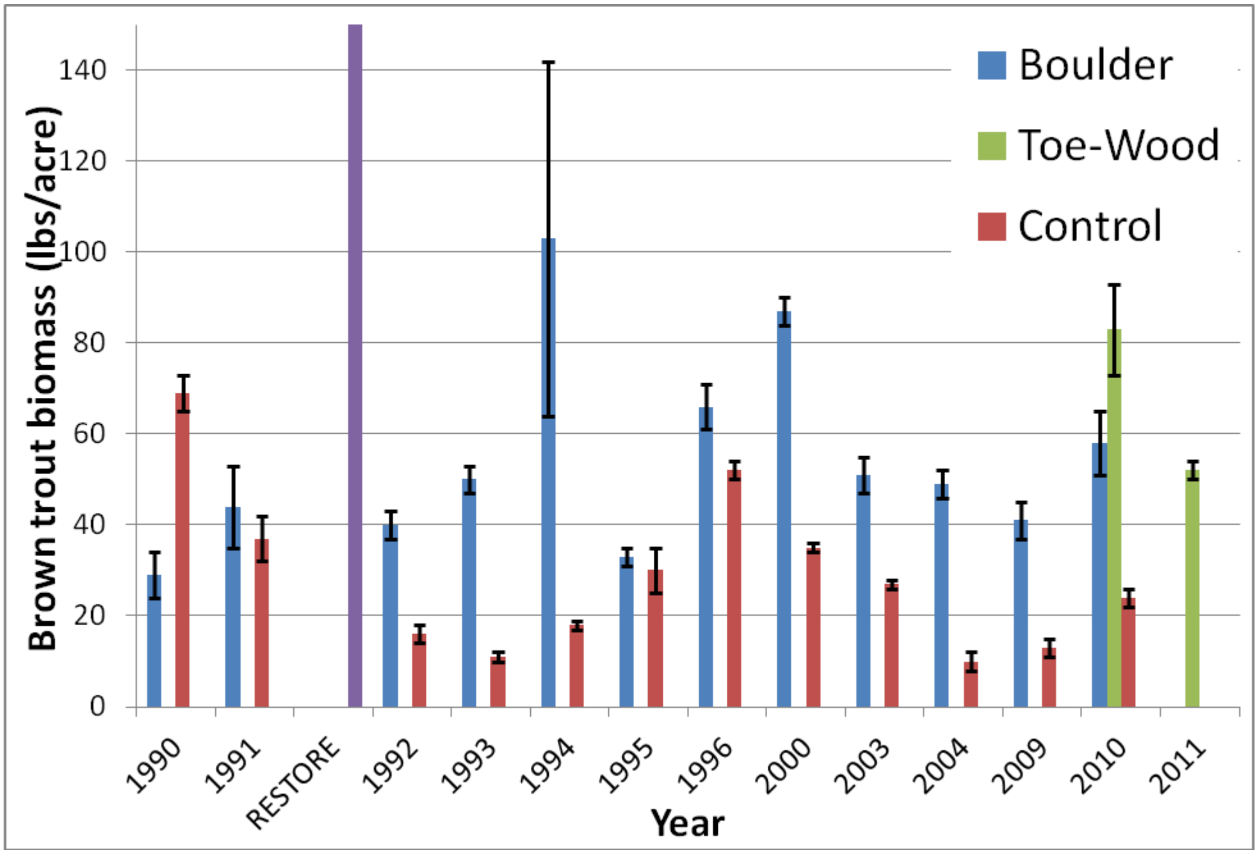

Figure 4. Fall fish sampling results for the Buckley Ranch Project. Brown trout biomass (lbs/acre) (± 95% C.I.) for control, treatment (boulder) and wood-toe treatment reaches located on the y-axis and sampling year for pre- (1990-1991) and post- (1992-2011) project completion on the x-axis.

<u>Upper Arkansas River:</u> Fish monitoring plans (including determination of long-term fish sampling locations) were completed for measuring fish response to stream habitat treatments. Data was collected this fall at six different sampling locations in the eleven-mile Upper Arkansas reach (Table 4.). Two new fish sampling stations (control and treatment sites) were established and sampled (using shore-based electrofishing techniques) in the Reddy Easement (upstream of the Highway 24 bridge). Four sites (two treatment and two controls) were sampled between the Highway 24 bridge and Kobe bridge with assistance from Greg Policky. This data will serve as baseline data for later comparison with fish sampling data once the project treatments have been implemented. This reach is unique in that some fish sampling sites will have over 16 years worth of baseline data collected prior to conducting stream habitat enhancement treatments. Data collected included fish population estimate data, length/frequency data, and fish species composition.

Table 4. Upper Arkansas River Project brown trout monitoring results for 2011. Brown trout biomass (lbs/acre) (± 95% C.I.) and adult density (# fish >100 mm TL/mile) data were collected for six sampling locations within the proposed Upper Arkansas Project reach to serve as baseline results for monitoring pre-and post-project treatment effectiveness.

Site Description	Site I.D.	Biomass (lbs adult brown trout/acre)	Density (# adult brown trout/mile)	Control/ Treatment	UTM X	UTM Y
Doc Smith property	AR-4	148 (±9)	1752 (±107)	Control	383599	4339230
Riffle location	Reddy Easement	79 (±4)	705 (±32)	Treatment	385232	4337264
Downstream Hwy 24 Bridge	AR-5	73 (±6)	1402 (±108)	Treatment	386680	4335650
Sinuous reach on perched channel	AR-5B	101 (±9)	824 (±73)	Control	386014	4335175
Pan-Arc reach; ½ mi upstream Kobe	AR-6A	79 (±10)	1069 (±180)	Control	386235	4332652
Across Hwy 24 near Moose Haven Inn	AR-MH	53 (±7)	856 (±114)	Treatment	386189	4332573
Below Kobe Bridge	AR-6	113 (±26)	1696 (±396)	Treatment	386963	4330755

Segment Objective 4: Conduct physical habitat surveys for use with best theoretical modeling techniques to assist with evaluating fish response to stream habitat manipulations.

ACCOMPLISHMENTS

South Fork of South Platte River: Two future fish habitat enhancement projects (Hartsel townsite and Upstream Badger Basin Headquarters) have been delayed due to funding limitations. Physical habitat surveys will be postponed until these projects are funded and a time-frame for construction is established.

Middle Fork of South Platte River/ Tomahawk SWA: Habitat surveys of reference reaches on the Tomahawk SWA were not completed during this segment period. Surveys will be completed during fall 2012. Physical habitat surveys from these long-term fish sampling sites ('Powerline" and "Above bridge" sites) will be useful in assisting with designs of future river restoration projects in South Park, CO. Physical habitat surveys will also be useful in helping explain differences in fish populations (e.g. brown trout biomass or density) between reference reaches compared to treated reaches and impaired sites.

A final as-built survey of Badger Basin SWA project was completed during the previous reporting period. Results are displayed and summarized under Federal Aid Project F-161-R17.

Job A.2. Effectiveness of Stream Aquatic Habitat Treatments within Functional Categories

Job Objectives: The effectiveness of specific habitat treatments will be evaluated by addressing the following research questions: how do fish utilize the treatment, what is the life expectancy of the treatment, what maintenance is required to keep the treatment functioning properly, what is the initial cost in terms of labor and materials to install the treatment, and how immediate is a given treatment able to provide the desired benefit? A variety of methods will be tested (snorkel survey, underwater videography and photography, PIT tag arrays, electrofishing sampling) to determine how fish utilize specific treatments. Individual treatments and project cross sections will be surveyed, monitored and inspected over time to determine their life expectancies, maintenance costs and how quickly they are able to provide the desired benefits. The material costs and length of time to install particular treatments will be recorded to determine overall costs for installation of particular treatments. Various treatments will be compared within functional groups to assess their relative costs and benefits.

Segment Objective 1: Fish utilization of various treatment types

During summer and fall months, conduct pilot studies using a variety of potential fish monitoring techniques including some or all of the following: PIT tagging, radio telemetry, snorkel surveys and underwater videography and photography for evaluating fish use of specific aquatic habitat treatments.

ACCOMPLISHMENTS

Ongoing studies using PIT tagging technology were initiated, investigating fish passage through WWP structures in Lyons on St. Vrain Creek and fish passage through engineered rock ramps (over diversion structures) on South Boulder Creek. Studies using PIT tagging technologies with fixed antenna systems were effectively applied in order to monitor fish movements within each of the these studies. PIT tagging shows promise as a possible technique to evaluate how fish utilize specific habitat treatments in future studies.

No pilot studies with radio telemetry, snorkel surveys, or underwater videography and photography techniques were used during this segment.

Segment Objective 2: Treatment longevity

Cross-sections at specific aquatic habitat treatment locations for which we have before, as-built and post-monitoring data will be re-surveyed to monitor treatment longevity and evaluate stability over time.

ACCOMPLISHMENTS

No cross-section monitoring surveys were conducted during this segment on reaches for which we have before, as-built and post-monitoring data.

We are currently working with Rod Van Velson (former CDOW stream aquatic habitat researcher) to assemble a list of monumented cross-sections at specific aquatic habitat treatment locations for which we have before, as-built and post-monitoring data. Once a list is assembled, sites will be re-surveyed to monitor treatment longevity and evaluate stability over time.

Segment Objective 3: Treatment maintenance and costs

Past project restoration costs will be evaluated with the following criteria: material and labor costs for various habitat treatments, length of time to install specific aquatic habitat treatments, maintenance costs associated with specific treatments and how quickly specific habitat treatments provide their intended function. Various aquatic habitat treatments will be compared within functional groups to assess their relative costs and benefits.

ACCOMPLISHMENTS

Data on past project restoration costs from various CPW stream restoration projects is currently being collected. We will continue to collect and analyze data related to treatment and maintenance over the next five years to try and determine how various habitat treatments compare using a cost/benefit analysis.

Job A.3. Angler Use in Restored Versus Un-restored River Channels

Job Objectives: Creel studies will be conducted to determine how angler use has changed in restored compared to un-restored river channels.

Segment Objective 1: Historic creel data

Aquatic biologists will be consulted to determine what data (if any) exist at proposed river restoration locations to quantify pre-restoration angler use.

ACCOMPLISHMENTS

Aquatic biologists were consulted for any existing creel data that might exist to quantify angler use in proposed river restoration reaches. No existing creel data were identified for use in evaluating changes in angler use from proposed river restoration reaches.

Segment Objective 2: Creel studies

Since no historic creel data exists, we will conduct creel surveys to quantify angler use specific to the un-restored river channel segment. Once stream restoration is completed, we will continue conducting creel studies to quantify angler use specific to the restored river channel segment for comparison. Creel studies were planned in pre- and post- treatment stream reaches during spring/summer 2012.

Upper Arkansas River Project: A creel study has been initiated and is currently underway within the Upper Arkansas River Project area (NRD project) from May-October 2012. Data collection is ongoing and results should be ready for analysis and summarized by the next reporting period.

South Platte Basin Projects: A creel study was not conducted in South Park this year due to logistical and scheduling conflicts with the area biologist who is currently conducting a separate creel study on lakes within the same geographic area.

Our plan is to conduct a creel study from May-October 2013 that includes the following sites: the reference reach (Tomahawk SWA), Badger Basin SWA (Middle Fork of South Platte below Badger Basin Headquarters), Badger Basin SWA (South Fork of South Platte above Badger Basin Headquarters), Buckley Ranch (South Platte River), Dream Stream (phase 1-3 and proposed final segment upstream of Elevenmile Reservoir).
Coordination will continue between George Schisler, Greg Policky, and Jeff Spohn to design creel survey tailored to surveying angler use in pre- and post-treatment stream reaches. A pilot study will be conducted with concealed trail camera systems as a possible technique for conducting creel studies in South Park.

Job A.4. Identification, Evaluation and Development of Fish Barriers for Protecting Colorado Fishes

Job Objective: Develop field and theoretical techniques for evaluating the barrier potential of instream obstacles. This study will involve multiple years of data collection statewide. Specific projects will result from consultations with aquatic biologists requesting assistance with measuring the barrier potential of instream structures. Examples include evaluation of fish barrier function to protect cutthroat trout populations from whirling disease or non-native salmonids, evaluation of native sucker and sport-fish passage through WWP structures and evaluation of diversion, low-head dam and culvert structures for passage of various Colorado fishes. Data collected from field sites will be useful in developing species-specific fish passage criteria, evaluating existing instream obstacles, refinement of monitoring techniques for fish passage at potential barrier sites and improvement of theoretical techniques for evaluating fish passage.

Segment Objective 1: Continue working with aquatic biologists to evaluate the barrier potential of instream obstacles to Colorado fishes. Develop publishable fish passage criteria for correcting potential barriers (i.e. culverts, diversions, WWP structures). Conversely, continue evaluations to assist with new barrier designs or modification of existing barriers to protect native Colorado sportfish from downstream threats.

ACCOMPLISHMENTS

FISH PASSAGE STUDIES: Evaluating Fish Passage for Two Engineered Rock Ramps

Title: Evaluation and Development of Fish Passage Designs

Techniques to modify existing diversion structures that will allow upstream and downstream migration for various trout species are being evaluated. This project includes an ongoing PhD study to determine the effectiveness of existing fishways (such as engineered rock ramps) for salmonids to develop new fishway designs, refine techniques to monitor fish movement at potential barriers and evaluate impacts of artificial in-stream structures such as White Water Park structures and water diversion structures on fish movement.

Project Need: Physical habitat alterations have been identified as one of the primary causes leading to declines and extinctions of fishes over the past century. Stream habitat alterations that limit sportfish dispersal and connectivity between populations include diversions, structures installed at road-stream crossings, and impoundments.

Background: Field work included reconnaissance of fishway sites on Boulder Creek and South Boulder Creek to determine suitability for deploying antenna arrays to monitor movement of tagged rainbow and brown trout through existing fishways. Suitable sites were identified on South Boulder Creek in Boulder, with cooperation from City of Boulder Open Space. Once field sites were identified, a pilot study was conducted at one of the locations in summer 2009. Movements of PIT tagged fish were monitored using a pair of antennae placed upstream and downstream of a diversion that has been modified to facilitate fish passage. The antenna system was successfully installed, tested and employed in the field and was used to monitor movements of wild salmonid fishes. A total of four additional antenna systems were purchased, installed, and used to collect fish passage data at two additional sites (one control site with no barrier to migration and one additional modified diversion structure). Fish passage studies on salmonid fish species at both modified diversion sites and the control site using PIT tag technology was completed by summer 2011. Topographic habitat surveys of three locations within Ashley's study reach were conducted on South Boulder Creek including McGinn Ditch, South Boulder Canyon Ditch, and a control reach located in between both diversions. In addition, detailed hydrologic and hydraulic measurements have been completed at these field sites. This physical habitat data will be used to design and construct scale models of rock ramp structures to evaluate performance of existing structures at CSU Engineering Research Center (ERC) lab. Scale models have been constructed and are currently being tested at the ERC.

During this research segment period, we provided project oversight to PhD candidate, Ashley Ficke on a project evaluating fish passage at two engineered rock ramps on South Boulder Creek, Boulder, CO. CPW has provided ongoing assistance with data analysis, study design, equipment purchases and acquiring necessary research supplies as well as ongoing technical and field assistance through the past year.

CPW has also provided assistance collecting fish (including brown and rainbow trout) for PIT tag studies from South Boulder Creek and assistance with re-installing PIT tag array systems after exceptionally high spring flows damaged antennae arrays. We have assisted with routine maintenance, installation of solar panels and changing batteries on PIT tag reading systems.

An additional component of this fish passage study will examine the influence of WWP structures on fish habitat quality (pool habitat formed by WWP structures), stream longitudinal connectivity, fish populations and fish passage. The goal of this research is to determine how WWP structures influence fisheries and therefore population stability. If current designs are found to negatively influence fisheries, we hope to modify white water park structure designs to allow upstream and downstream migration for both game and non-game species. A CSU engineering Master's student is currently working with CPW to study the effects of these WWP structures related to the above stated project goals.

This following is the executive summary of the final progress report for Ashley's project. Notable project accomplishments are listed below. A full report will be provided for Colorado Parks and Wildlife after the project is completed in the spring of 2013.

Project Goals

1) South Boulder Creek field study: Few fishways have been constructed in transition-zone streams, and to our knowledge, even fewer of these have been tested for efficacy. Our first project goal was to use PIT tags and antenna arrays to measure fish passage rates across two agricultural diversions that have been modified to provide fish passage. These movement rates were compared to movement rates across a control reach.

2) Fish swimming performance characterization: Swimming performance data on small-bodied fishes is relatively sparse but required for the successful design of effective fishways. Because it is not practical to measure the swimming ability of every small-bodied Great Plains fish, our second project goal was to develop a model to predict maximum aerobic and anaerobic swimming velocity of small-bodied fishes based on morphological and physiological traits.

3) Rock ramp fishway testing: There is little standardization in the design of grouted rock ramp fishways, and the sole use of average water column velocity as a design criterion ignores fish swimming behaviors and the effects of small-scale turbulence on small- bodied fishes. Therefore, our third project goal was to test rock ramp models under laboratory conditions and modify substrate placements to affect near- bed velocities and turbulence, as well as average water column velocity. The effects of near-bed velocity, turbulence (measured as Reynolds stress), and average water column velocity will be related to the upstream passage success.

Project Accomplishments

1) South Boulder Creek field study: We monitored six passive integrated transponder (PIT) tag antenna arrays in South Boulder Creek from May 2010 through July 2011. We measured upstream fish movements across a small boulder vane with no vertical drop (Control Reach) and compared them with fish movements over two engineered-rock ramp structures located at the McGinn Diversion and the South Boulder Ditch Diversion.

We tagged 1,153 individual fishes, of which 660 were subsequently detected at one or more antennae, and 137 (12%) were detected moving upstream across at least one pair of antennae. Most individuals only moved across a single set of antennae, but some moved across multiple structures (Table 5).

Table 5. Upstream movements detected in South Boulder Creek. The first three movements involve crossing a single structure, the following two movements involve crossing two structures, and the last movement involves crossing all three structures in the study reach.

Structure(s)	**Number of Movements**
McGinn Diversion Only	58
Control Reach Only	57
South Boulder Ditch Diversion Only	15
McGinn Diversion and Control Reach	2
Control Reach and South Boulder Ditch Diversion	10
McGinn Diversion, Control Reach, and South Boulder Ditch Diversion	4

Although the small number of detected movements limits inference, movements across the lower structure were higher in October and April and lower in May and June than they were at the other two structures (Figure 5).

Movement rates are not currently separated by species because of the small number of detected movements and the fact that detection probabilities at the antenna were not species-specific. However, species-specific passage rates will be presented in the final report to CPW.

An MS Access database with the PIT tag detection data was completed in February 2012 and individual capture histories for each fish have been prepared. Individual capture histories have been entered into Program MARK for a multi-state analysis, and some preliminary models have been run. These models continue to be refined. Upstream movement rates across the three structures will be compared to determine whether they are significantly different. Additional analyses involving seasonality of movement and long- distance movement rates are also planned. Data analyses will be complete by the end of July 2012 (Table 6).

Preliminary results were presented at the 2nd annual Fish Passage Conference in Amherst, Massachusetts in June 2012, and preparation of the associated dissertation chapter and manuscript have commenced.

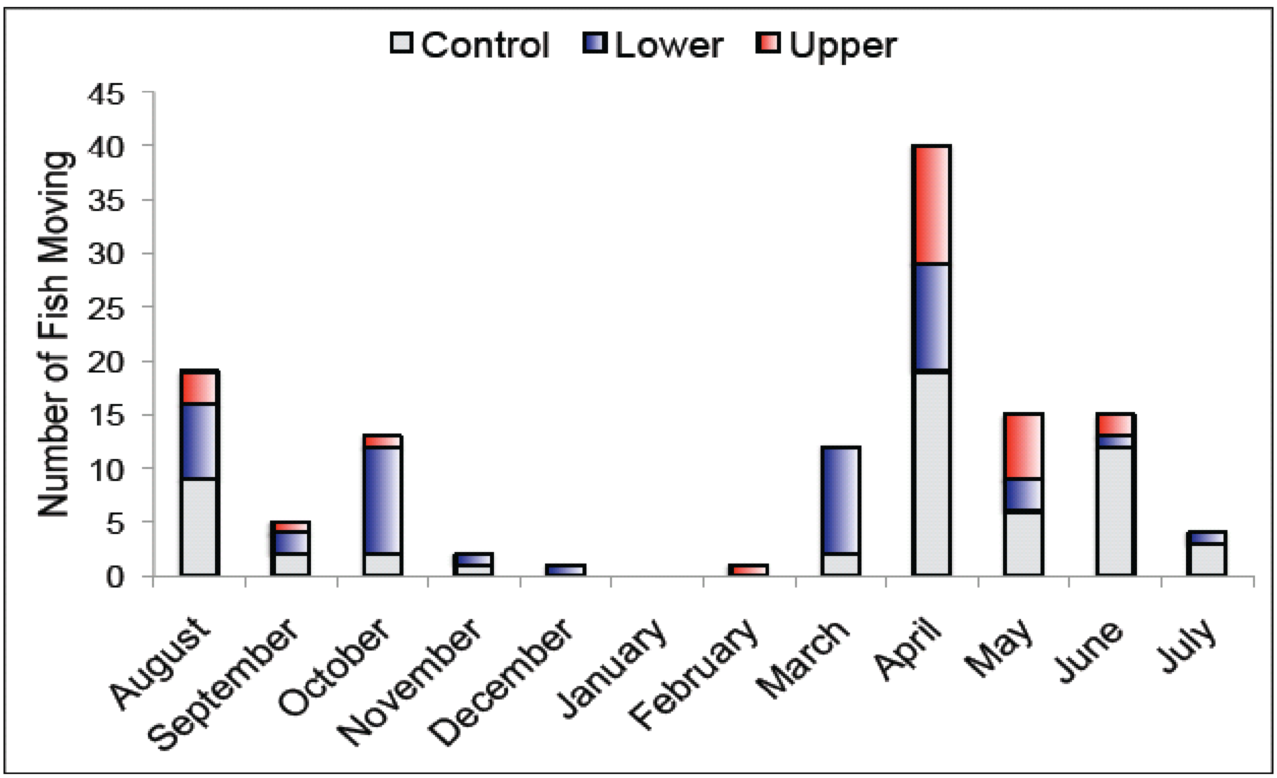

Figure 5. Seasonal pattern of movement at two structures and the control reach on South Boulder Creek.

2) Rock ramp fishway testing: Construction of the wood framing of the rock ramp model at the Engineering Research Center at CSU is complete. Methods of tracking fish and measuring hydraulic parameters such as near-bed velocities and turbulence are still being refined, and substrate will be added to the ramp within the next week. Rock ramp tests with fish will begin in late July or early August and should be complete by the end of December (Table 6).

The fishes required for the predictive swimming model and the rock ramp experiments at the ERC are currently being collected. We have sufficient numbers of approximately half of the species needed for the swimming model. The ERC experiments will require a large number of individuals, so collection for these is ongoing.

Table 6. Timeline for completion of project components for CPW.

Task	Jul 2012	Aug 2012	Sep 2012	Oct 2012	Nov 2012	Dec 2012	Jan 2013	Feb 2013	Mar 2013
Field study data analyses in Program MARK	■								
Predictive swimming performance model trials (CAT tests)	■	■	■	■					
ERC rock ramp construction and hydraulic measurements	■								
ERC tests of fish passage success		■	■	■	■	■			
Swimming performance data analyses				■	■				
ERC rock ramp data analyses						■	■		
Submission of final report to CPW									■

3. Training: The graduate student on the project, Ashley Ficke, has been advanced to candidacy for her Ph.D. At this point, she needs to finish data collection and analysis, and preparation of her dissertation before she receives her degree. She expects to graduate in May 2013.

The project has supported a number of undergraduate students, providing them with valuable field and laboratory training in fisheries biology. These undergraduates are listed below.

Name	Current Status
Anderson, Jordan	Graduated in 2011. Worked as a 6-month technician for S. Brinkman and as a post-graduate technician for C. Myrick on a related project (M. Kondratieff's whitewater parks project).
Callison, Justin	Working to complete his B.S. in fisheries biology at CSU. Has worked as a 6-month temporary CPW technician for M. Brandt and is currently working for M. McGree.
Hansen, Adam	Graduated in 2008. Subsequently completed a M.S. at the University of Washington and is pursuing a Ph.D. at the same institution.
Herdrich, Adam	Graduated in 2012. Currently working as a temporary CPW technician with Boyd Wright. Also working on an independent study on stonecat culture and reproduction with C. Myrick, R. Fitzpatrick, and N. Vieira.
Oles, Kristin	Graduated in 2012.
Pruitt, Dylan	Graduated in 2010.
Swarr, Tyler	Currently working on the project.
Underwood, Zachary	Graduated in 2011. Worked as a post-graduate technician for C. Myrick on a related fish swimming project, and has worked as a CDOW technician for H. Crockett and R. Fitzpatrick. Entering the M.S. program in fisheries at the University of Wyoming.
Wardell, Jon	Currently working on the project.
Wilson, Nick	Currently working on the project.
Winkelman, Rennie	Ms. Winkelman received a Hutton Scholarship from the American Fisheries Society in 2012 and will be working on this project, among others, before she starts her B.S. program at the University of Montana in Fall 2012.

Project Publications

Ficke, A. D., M. C. Kondratieff, and C. A. Myrick. 2011. The effects of PIT tagging on the swimming performance and survival of three nonsalmonid freshwater fishes. Ecological Engineering DOI:10.1016/j.ecoleng.2011.07.011.

FISH PASSAGE STUDIES: White Water Parks

Title: Potential Problems Associated with White Water Parks in Colorado

Background and Context

Colorado is the epicenter for WWP development and design nationwide with Colorado boasting more WWPs than any other state. Colorado has a total of 21 existing WWPs with another ten WWPs proposed by various communities across the state. WWPs do provide contributions to local communities by providing revenue from tourism, promoting public interest in rivers and creating exciting new recreational opportunities. However, with an increasing number of proposed and constructed WWPs and with the rapid evolution of new designs optimizing performance of hydraulic features, there is a need for fisheries managers to keep abreast of how WWPs influence aquatic organisms, natural river processes and anglers. To date, very few WWPs have been monitored and little information exists to assess their potential impacts on natural river processes and their associated biota. CPW has recently begun monitoring a small number of WWPs in Colorado. Based on this limited but growing body of evidence, we have identified a number of concerns surrounding WWPs including: 1) problems with impaired or blocked upstream passage for fish and other aquatic organisms, 2) degradation and habitat loss for fish and other aquatic organisms, 3) disruption of natural river processes and angler/boater conflicts.

Current research topics include the following (most are ongoing):

I. Fish Passage: CPW is concerned about the potential for blocked or impeded upstream passage for fish and other aquatic organisms within WWPs. The ability for fish (and other aquatic organisms) to make un-impeded movements up- or downstream to access important habitat are critical to maintaining populations over time.

Currently, CPW is actively studying the following aspects of WWPs related to fish passage in order to improve existing fish passage prediction models and come up with better tools for assessing upstream fish passage at WWPs (existing and proposed designs).

- Determining if the presence of WWPs affect the upstream movement rates of fish within streams and under what flow conditions movement may be inhibited (PIT tagging field studies).
- Evaluating whether upstream movement is restricted to specific species and life stages.
- Identifying preferred movement pathways within WWP structures (e.g. are fish utilizing the low flow notch or wing wall areas).
- Identifying what specific hydraulic conditions explain variation in upstream movement by species and life stage.
- Determining the ability of Fish Xing and other 1-dimensional hydraulic modeling programs (HEC-RAS) to reproduce the hydraulic conditions that are actually occurring at WWP structures. Evaluating other 2-D and 3-D model performance as well.

- Analyzing whether a 1-dimensional model in combination with published fish swimming data can accurately predict when fish movement is possible.

- Conducting detailed swim performance studies on native Colorado stream fishes including those occurring in Front Range river systems such as: stonecat, suckermouth minnow, creek chub, white sucker, longnose sucker, brook stickleback, green sunfish, northern red belly dace, sand shiner, longnose dace, flathead chub, Iowa darter, Johnny darter, orangethroat darter and plains killifish.

CPW believes that any WWP structure that is placed in a stream should improve or have no negative influence on aquatic organism passage. Some of the concerns we have identified related to this point include the following:

1. Grouted Structures: The use of grout to secure boulders in place and create hydraulic conditions necessary to optimize play waves present challenges to aquatic organism passage. Most natural stream beds have spaces between particles (interstitial spaces) and along the lateral edges of the channel boundary that aquatic organisms use for habitat including escape from predators, refuge from high velocities, feeding areas, and as “roughened”, low-velocity corridors for making movements up or downstream. Most of the WWP structures throughout the state incorporate grout into their designs. This practice eliminates naturally-occurring interstitial spaces between particles, limits or eliminates low-velocity or roughened passage routes, and greatly increases water velocities through the structure (velocities exceed those found in adjacent natural reaches up or downstream).

Grout (or cement) used in active river channels also require frequent maintenance and supervision. River channels are by nature active and require some degree of freedom to move horizontally within their adjacent floodplain areas. As natural rivers adjust or move over time, rigid concrete does not allow the ability for rivers to move particularly laterally. Often the river will “flank” the structure (erode behind the structure and bypass the structure) or concrete material will break apart and fracture leading to costly maintenance and frequent repairs. This is why many WWPs in Colorado have heavily-armored boulder banks or terraces associated with each WWP structure to prevent the river from moving laterally and to “fix” the river in a rigid sense (Figure 6).

Figure 6. Typical lateral bank boulder armoring associated with WWP structures near Buena Vista, CO.

Velocities measured within WWP structures, especially during low flow periods when water is fully contained within a narrow cross-sectional area, have frequently exceeded 10 ft/second (Figure 7). These velocities are well above published swimming velocities for even the strongest swimming species (e.g. rainbow trout, Figure 8). In addition, fish that are adapted to natural conditions within a given stream reach are not adapted to these high velocities. Such high velocities are outside the range of expected velocities for the natural stream reaches where these species live.

A

B.

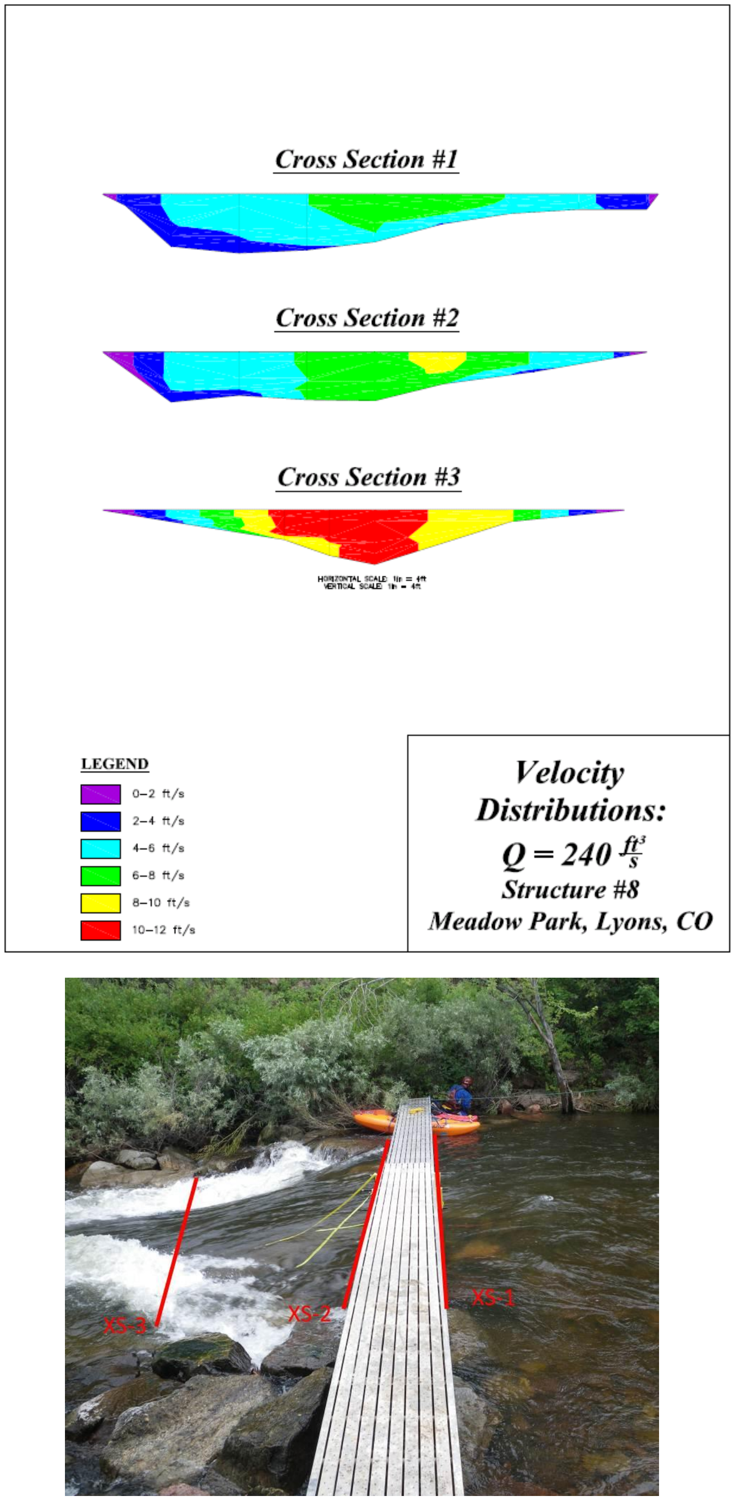

Figure 7: A. Velocity distribution profile through a typical WWP structure from St. Vrain Creek, Lyons, CO. Velocities were recorded using a flow meter corresponding to a discharge rate of 240 cfs. B. Locations where each of three cross-section velocity profiles were measured.

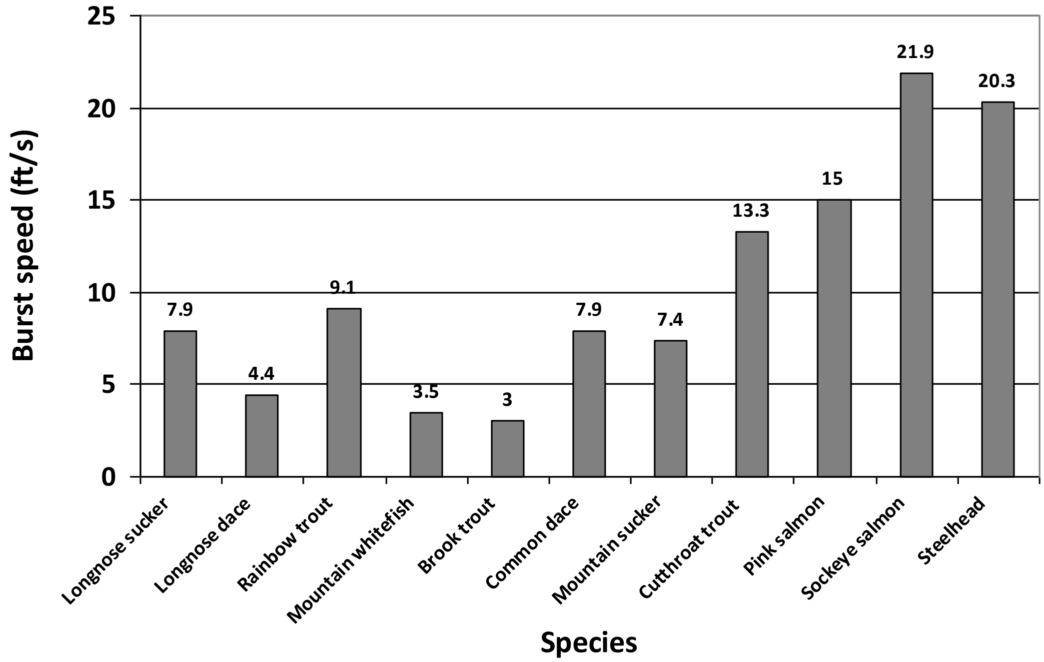

Figure 8: Maximum fish burst swim speeds from published sources. Burst swim speeds are commonly defined as the maximum speed a fish can sustain for no more than 20 seconds. Many Colorado fishes cannot swim faster than 10 ft/s.

2. Velocities/Slopes/Depths: Many of the typical WWP structures we have surveyed have velocities, slopes, and depths that are outside expected ranges when compared with natural stream channels of the same geomorphic context. For instance, most of the surveyed slope measurements for chute-type WWP structures exceed 5%. Some of the structures have slopes as high as 12% (Figure 9). Under these conditions, velocities can reach as high as 13 ft/second (measured). We do not encounter velocities anything close to this high when surveying natural streams located in the same vicinity and similar geomorphic context. Fish are adapted to the natural conditions in which we find them. Why would we expect them to survive or prefer conditions which are well-outside of these conditions?

In addition, depths can also become extremely shallow to the point that adult fish body depth is greater than the water depth inside the WWP structure. According to the Colorado Department of Transportation's (CDOT) fish passage criteria for culverts, a depth of 6 inches or more is required for trout less than 20 inches total length and a depth of 8 inches or more is required for trout greater than 20 inches total length. We have measured depths shallower than 6 inches at many WWP structures across the state during periods of low or base flow, which may persist at some locations for as much as 9 months out of the year.

Many of the structures we have surveyed do not have sufficient lateral roughness (such as protruding boulders or angular rock) to provide velocity refuge for fish to rest as they try to ascend structures going upstream. Most structures observed in the field have smooth rock or grouted surfaces that provide little to no roughness to break up lateral boundaries within the low flow notch (or chute).

As we have surveyed WWPs across the state, another common observation we have made is that many of these structures share similar hydraulic characteristics as concrete box or ellipsoid culverts under low or base flow conditions. For States that have established fish passage criteria, most have standards that require fish passage devices such as engineered baffles to provide resting areas for fish in culverts that are higher than 5% slope. The Colorado Department of Transportation (CDOT) has requirements for culverts as listed in Chapter 15, section 15.5 of their Drainage Design Manual. Their fish passage design criteria require that culverts be installed at slopes less than 0.5% if at all possible. For locations that require culvert installations between 0.5 and 5.0%, culverts are required to contain sills, baffles or slot orifices to provide fish with resting areas as they journey upstream. For culverts installed at slopes greater than 5%, a separate special fishway (i.e. fish ladder or bypass channel) is required. Colorado is not alone when it comes to having established culvert fish passage design criteria. Other states such as Oregon, Washington and California operate under similar conditions with established fish passage criteria similar to Colorado in order to protect their fish and other aquatic resources.

The range of slopes, velocities, and depths that we have observed at WWPs in Colorado well exceed the acceptable range of tolerances for culvert designs required by states such as Colorado, Oregon, Washington, and California. If many States do not allow culverts to be installed steeper than 5% to protect upstream fish passage, an argument could be made that WWP structures should adhere to similar principles since they function identically to culverts (hydraulically), especially during periods of low or base flows when water is completely contained within the low flow notch.

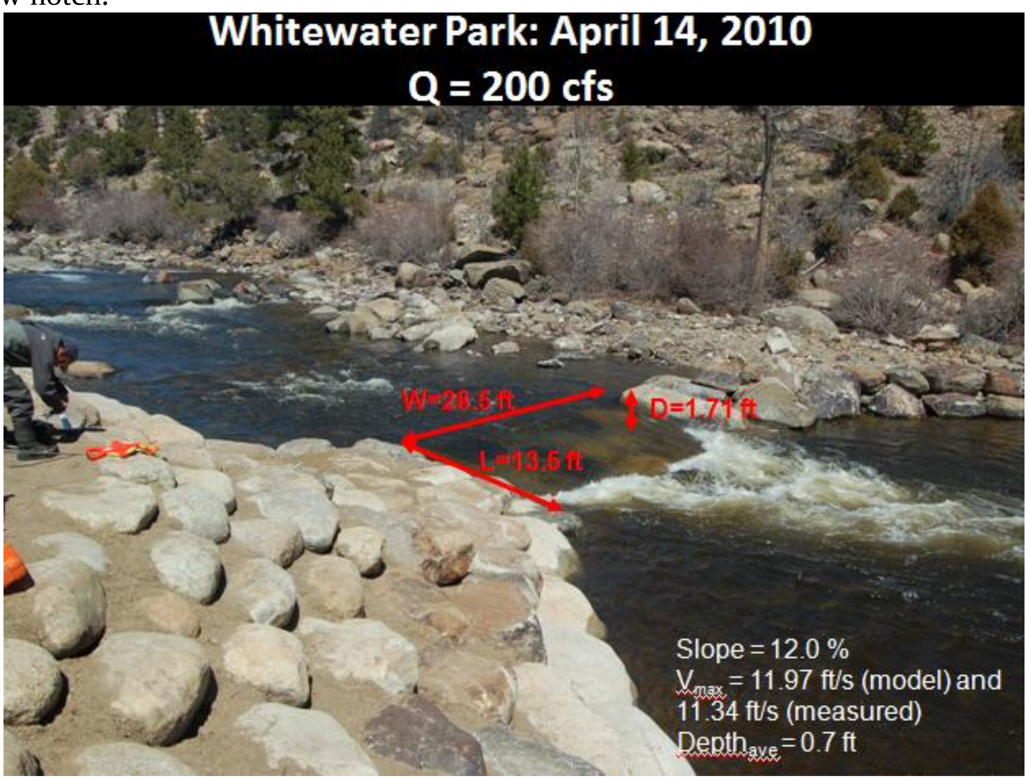

Figure 9. Typical WWP structure in the Arkansas River, Buena Vista, CO. This structure had a slope (surveyed) of 12%, maximum measured velocities of 11.3 ft/s, and water depths of approximately 0.7 ft measured at base flows of 200 cfs.

II. Fish Habitat and Disruption of Natural River Processes: We make the assumption that fish biomass and fish density are reliable indicators of habitat quality. In other words, the higher the fish biomass and densities, the better the quality of the habitat. CPW is concerned that fish habitat is negatively influenced by WWP structures. CPW biologists have collected fish data from selected WWP areas across the state for several years. Many of these WWP locations have lower fish biomass and fish densities than expected compared to adjacent natural stream reaches located up- or downstream. This is in spite of the fact that WWP pools are often much deeper and larger (volume) than natural pools found in the same vicinity. The fact that many of the pools associated with WWPs contain lower fish biomass and densities than natural pools in the same vicinity is unexpected because a number of publications have documented a strong positive correlation between fish biomass/densities and maximum pool depth. There are several explanations for why fish biomass and densities might be lower in WWP stream reaches than adjacent natural stream reaches, which may be explained by one or more of the following hypotheses:

- Upstream fish passage is impeded by WWP structures thereby preventing colonization of pools from fish trying to swim upstream (see above section titled "Fish Passage").
- Characteristics of WWP pools cause fish to avoid them and these conditions are different from natural pools.
- Habitat characteristics responsible for creating or maintaining fish food has been negatively influenced by WWP structures thereby lowering the overall carrying capacity for fish living within the WWP reach.
- Fish living in WWP pools are more vulnerable to overharvest from anglers than fish living in natural pools.

Currently, CPW is actively studying the following aspects of WWPs related to fish habitat quality:

- Assessing pool quality based on fish sampling from within selected WWP, habitat, and control reaches during the spring and fall.
- Assessing pool quality based on pool velocity profiles from within selected WWP, habitat and control reaches using ADCP (Acoustic Doppler Current Profiler) technology and various flow meter devices (Marsh-McBirney flow meter and Acoustic Doppler Velocimeter/ADV).
- Conducting detailed physical habitat surveys to compare characteristics of stream bedforms within selected WWP, habitat and control reaches using GPS survey-grade equipment.

We plan to investigate these possible explanations for why fish biomass and density is lower in WWP pools than natural pools in the same vicinity.

1. Monitoring pool habitat quality via fish sampling comparing WWP structures vs. habitat enhancement structures vs. natural pools: We are currently monitoring fish biomass and densities of pools located within four separate stream reaches within the vicinity of a WWP located on St. Vrain Creek in Lyons, CO. The main stem of St. Vrain Creek merges with the South Fork of St. Vrain Creek in the heart of the town of Lyons. We have set up the monitoring study so that we have two paired comparison stream reaches. A WWP reach located on the main St. Vrain Creek is paired with an upstream control reach located approximately 0.5 miles upstream from the WWP. In addition, a habitat reach where ungrouted boulder/rock cross vane structures were installed to provide enhanced pool habitat for fish (deeper and larger pools) is located on the South Fork of the St. Vrain Creek. This site is paired with an upstream control reach located about 0.10 miles upstream of the habitat reach. Within each of the four study reaches, a total of three pools were selected for monitoring purposes. The pools associated with the upper- and lower-most structures within the WWP and habitat reaches were selected. An additional pool located in the middle of each reach was included as well for a total of three pools per reach. For control reaches, pools were selected that were representative of natural pools located within the same geomorphic context as the WWP and habitat reaches. A total of three pools were selected within each control reach. Therefore, we have a total of 12 pools that we are monitoring as part of this study (Figure 10).

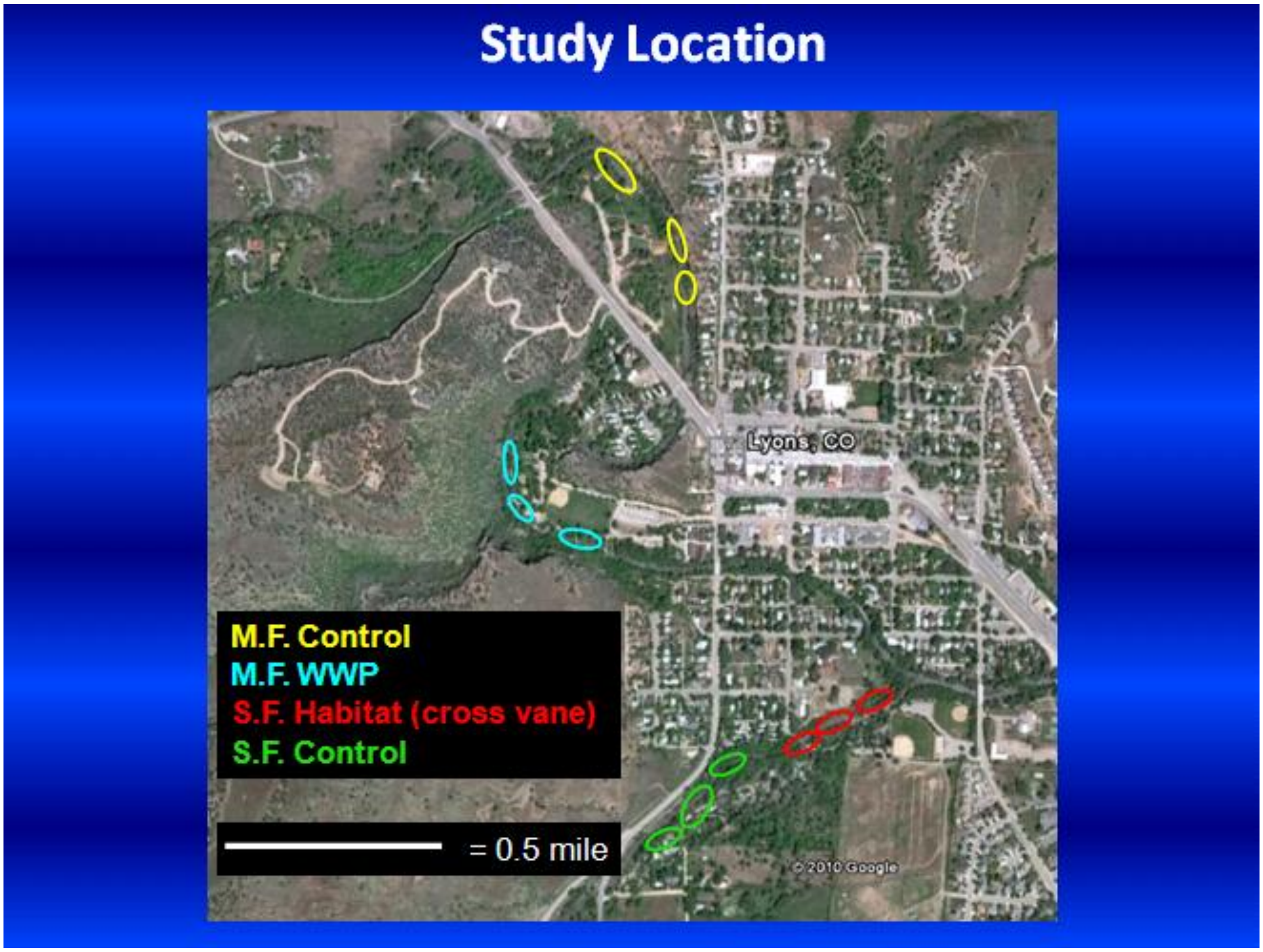

Figure 10. Study location in Lyons, CO. A total of 12 pools are being monitored over time as part of a study evaluating habitat quality of pool associated with grouted WWP structures and un-grouted habitat enhancement structures.

Results so far have indicated that fish biomass and densities are higher for pools located within the habitat reach than the adjacent upstream control reach as one might expect. However, the same relationship does not hold true for the WWP and paired control reach comparison. Fish biomass and densities within the WWP reach were much lower than the adjacent upstream control reach. This is the exact opposite of what we would have expected based on our understanding of the relationship between fish biomass/densities and maximum pool depths (Figure 11). There is evidence that fish biomass increases with increasing pool depth when comparing all six of the natural control pools (Figure 12). Fish sampling will continue for all 12 habitat sites during the spring (April) and fall (October/November).

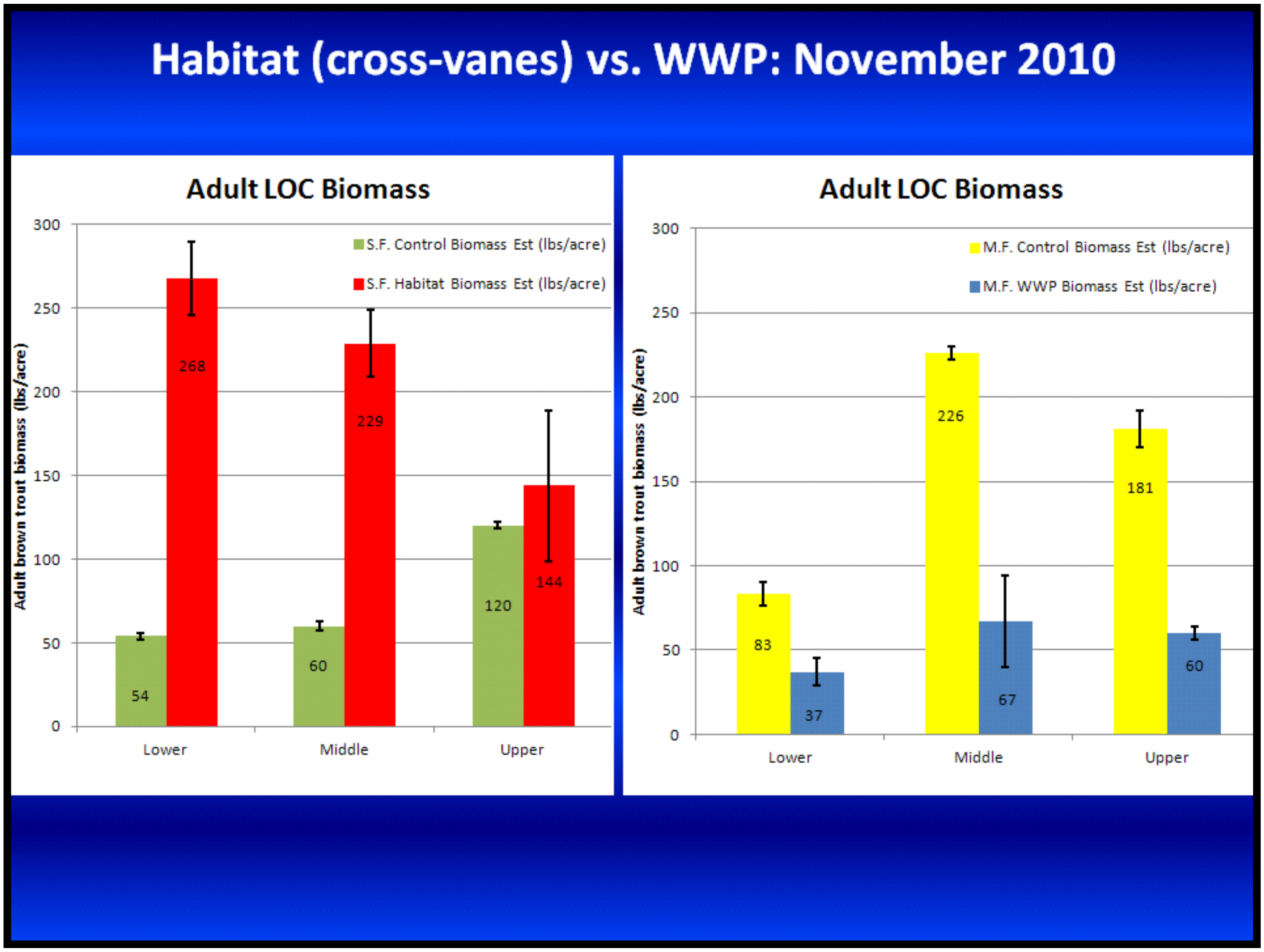

Figure 11. Results of fish population monitoring using electrofishing sampling gear. A paired comparison was made on South St. Vrain Creek between ungrouted habitat enhancement structures (red bars labeled “Habitat”) and adjacent upstream natural pools (green bars labeled “Control”). Similarly, a paired comparison was made between grouted WWP structures (blue bars labeled “WWP”) and adjacent upstream natural pools (yellow bars labeled “Control”). Brown trout biomass measured in lbs/acre appears on the y-axis. Each of the three pools within each study reach is labeled on the x-axis as “Lower,” “Middle,” and “Upper.”

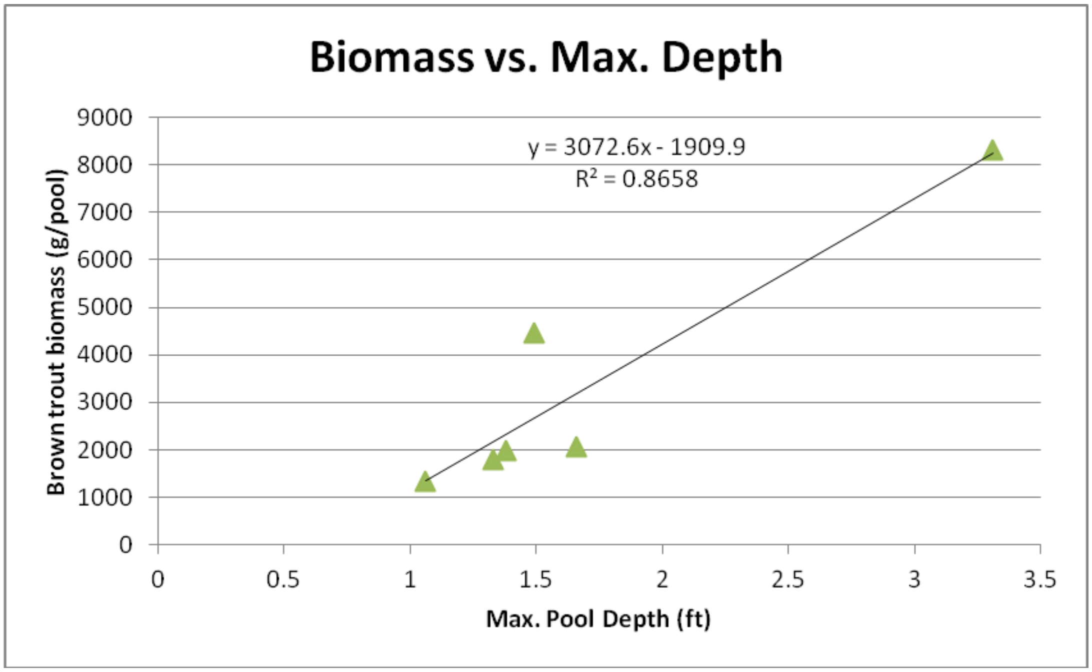

Figure 12. Relationship between brown trout biomass in grams/pool versus maximum pool depth in feet for natural (or control) pools. Data from monitoring shows a positive correlation between fish biomass and maximum pool depth, suggesting that fish biomass increases with increasing pool depth.

We also were able to sample the WWP pools during the peak spawning period for brown trout in November 2011. During this time, there is net-directed upstream movement of adult brown trout seeking out optimal spawning conditions located further upstream in the watershed. We found that there was nearly twice the biomass of brown trout in the lower-most pool than either the middle- or upper-most pools (Figure 13). We surveyed all three of the pools and found that all of them had very similar maximum pool depths, pool volumes, and pool surface areas. With all things being (nearly) equal, why would there be more fish in the lower-most pool compared to the two upstream pools given that brown trout were motivated to move upstream at this time (behaviorally)? We came up with two explanations: 1) brown trout movements were impeded or blocked by the lower-most WWP structures so they were getting crowded at this lower pool or 2) brown trout were massing at the lower-most WWP pool because some other fish species (forage fish) that were trying to move upstream during the same time period were getting stuck (impeded or blocked) at this location. This provided brown trout opportunity to feed on these forage fish since these fish were blocked from moving upstream from this point.

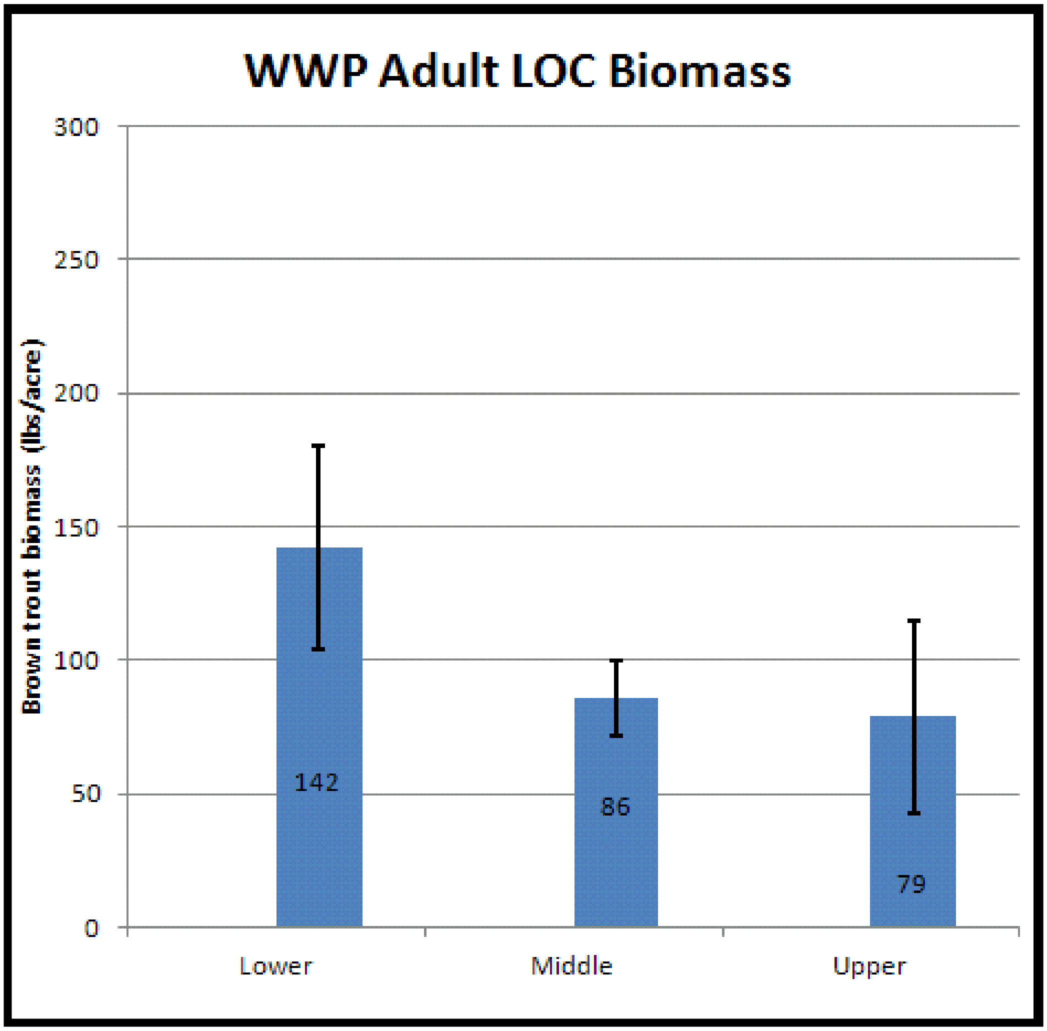

Figure 13. Results of fish population monitoring using electrofishing sampling gear. Blue bars represent brown trout biomass in WWP pools. Brown trout biomass measured in lbs/acre appears on the y-axis. Each of the three pools within each study reach is labeled on the x-axis as "Lower," "Middle," and "Upper."

2. Assessing pool habitat quality by comparing detailed velocity profiles of WWP structures vs. habitat enhancement structures vs. natural pools using an Acoustic Doppler Current Profiler (ADCP) and flow meter devices (Marsh-McBirney flow meter and Acoustic Doppler Velocimeter/ADV): CPW has observed differences in how pools associated with grouted WWP structures, ungrouted cross vane structures and natural pools function hydraulically.

WWP pools: In general, pools associated with WWP structures are categorized as "contraction-scour" pools. Water accelerates rapidly as it plunges steeply though the smooth grouted throat of the structure and enters the pool below. Strong reverse eddies are formed as water swirls back in an upstream-direction at either side of the downstream pool. We have measured velocities of these reverse eddies up to 3 ft/second. Strong turbulence and chaotic forces operate to scour the bed downstream of the grouted structure. Substrate characteristics of the pool bed are strongly bimodal with very coarse material downstream of the throat of the structure and fine/sandy material deposited on the lateral edges in association with reverse eddy action. Very little particle sorting occurs in between. A hydraulic jump occurs as water accelerating through the throat of the structure enters the static portion of the pool downstream. Based on our observations, there appears to be very little pool habitat that includes zero (or near zero) velocity conditions that fish prefer as holding habitat to minimize energy expenditures.

Habitat enhancement pools: In general, pools associated with un-grouted cross vanes or vortex structures were “leaky” with gaps between boulders (laterally) and also with gaps between the header and footer rocks (vertically). There was still an abrupt drop over the structure, but strong reverse eddies were not readily visible in pools below structures. Hydraulic jumps were also not visibly present. We conducted a study comparing pools below these habitat enhancement structures and WWP pools using an ADCP. This will allow us to look at velocity and turbulence characteristics between each structure type and how each pool-type behaves hydraulically. This should help us in understanding how these various structures create different pool conditions that may or may not be preferable to fish. We also have developed 3-D models comparing natural pools, habitat enhancement pools, and WWP pools that will help us understand otherwise complex hydraulic differences between these sites and how those differences relate to fish densities and biomass.

Natural pools: In general, natural pools were shallower than either WWP or habitat enhancement pools. Pools were primarily formed by lateral scour forces and maintained by secondary flow cell circulation with deposition occurring to the inside bend and scour forces operating along the outside bend. Natural pools were characterized by a steep drop (run) transitioning into the pool followed by a gradual adverse slope heading toward the back of the pool and the riffle crest. This adverse slope allowed for sediment to gradually sort itself out. Finer particles were located within the deepest part of the pool and gradually particle sizes increased as the channel bed rose to meet the riffle crest. This sorting is what provides ideal spawning materials for trout and other fish species.

Many of the WWPs we surveyed had pool-to-pool spacing that was outside the range of expected values based on the geomorphic context of the stream (pools were often located too closely together).

WWP structures require a significant drop elevation to optimize hydraulic characteristics of the play wave. The drop in elevation in essence comes from the drop in elevation from the riffle crest to the head of the next run (in natural streams). Natural channels have riffles that are characterized as having a gradual drop in elevation over a long horizontal distance. This allows for a very large surface area that creates ideal habitat for a variety of aquatic organisms, including many insects which compose a significant portion of trout diets in streams. Conversely, WWP structures have a very rapid drop over a very short horizontal distance. In addition, most of the drop occurs over a grouted surface that has little no space for aquatic organisms to inhabit. This result along with the very close spacing of consecutive pools results in very little riffle habitat existing within the WWP reach. Our April fish sampling provides a good snap shot of how fish are distributed throughout the low-flow winter and early spring months prior to run-off. Fish have had all winter to distribute themselves and the carrying capacity of each pool is set based on the quantity and quality of food flowing into each pool from upstream. Interestingly, we found from monitoring data that the upper-most WWP pool contained the highest biomass of fish and that each subsequent pool monitored had lower biomass as one progresses downstream. This supports the idea that riffle quality is diminished in the WWP reach with the poorest quality in the downstream-most location. A similar relationship was not apparent within the habitat enhancement reach (see Figure 14.). We plan to investigate this further by directly sampling aquatic invertebrates (drift) at each study site within the WWP reach.

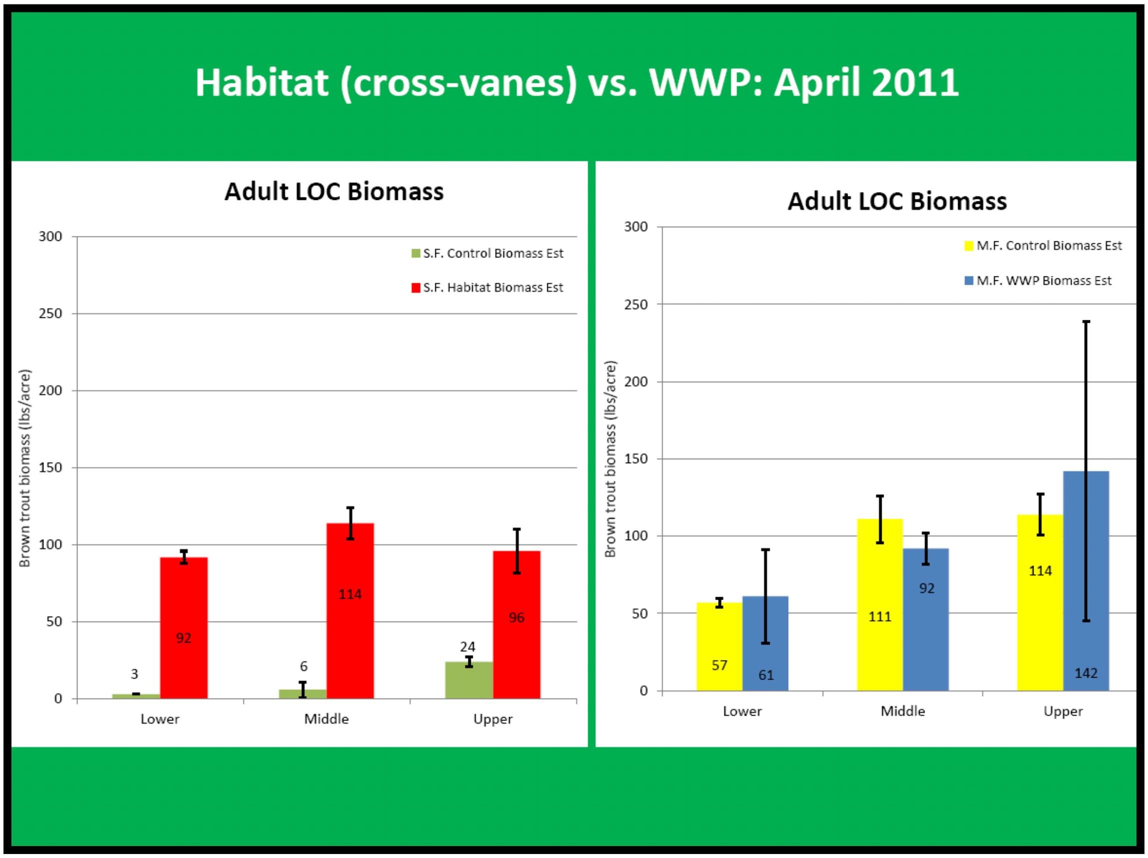

Figure 14. Results of fish population monitoring using electrofishing sampling gear. A paired comparison was made on South St. Vrain Creek between ungrouted habitat enhancement structures (red bars labeled “Habitat”) and adjacent upstream natural pools (green bars labeled “Control”). Similarly, a paired comparison was made between grouted WWP structures (blue bars labeled “WWP”) and adjacent upstream natural pools (yellow bars labeled “Control”). Brown trout biomass measured in lbs/acre appears on the y-axis. Each of the three pools within each study reach is labeled on the x-axis as “Lower,” “Middle,” and “Upper.” Notice the blue bars indicate that brown trout biomass decreases upstream to downstream through the WWP reach.

III. Conflicts Between Anglers and Boaters: CPW is studying the following aspects of WWPs related to angler and boater interactions.

We are currently assisting biologists with creel studies with the goal of determining how angler use and fishing quality is affected at and around WWPs. Kendall Bakich (CPW aquatic biologist) and George Schisler have assisted to design a creel study that serves two purposes: 1) to collect baseline angler use data to monitor how angler use changes before, during and after WWPs are constructed (Roaring Fork River, Basalt) and 2) determine how angler use changes based on proximity to an existing WWP (Colorado River WWP in Glenwood Springs).

1. Conducting creel surveys to compare angler use within or in the vicinity of WWPs and adjacent natural areas up- and downstream of selected WWPs.

Researching existing creel survey reports and boater surveys to determine preferences of both user groups

SUMMARY

While CPW is still collecting data on WWPs and their potential influence on fish passage, fish habitat quality, influence on natural stream processes, and potential conflicts between boaters and angler, we have collected a substantial amount of preliminary information on each of these topics to provide some evidence of the negative impacts of WWP structures.

A logical follow-up to this evidence is that many streams are already impacted by high impassable diversion structures that prevent fish passage upstream. This is true. However, recent work by Ashley Ficke has shown that fish passage structure designs constructed at diversion structures on South Boulder Creek in Boulder, CO (6+ vertical feet) have shown the ability to successfully pass trout, native suckers, and even native dace (weakest fish swimming species in the entire assemblage for South Boulder Creek). Her research suggests that it is possible to re-connect stream segments upstream and downstream of very high diversion structures to allow for fish to move through these previously insurmountable structures.

STUDY PLAN B: TECHNICAL ASSISTANCE

Job B.1.   Stream Restoration Assistance to CPW Personnel and Other State and Federal Agencies

Job Objective: To provide expertise, consultation, evaluation and training related to stream habitat restoration project identification, selection, design and permitting to CPW and other state and federal personnel as requested.

Segment Objective: CPW and other state and federal personnel are frequently in need of technical assistance related to stream habitat restoration projects. As the need arises, technical assistance related to stream habitat restoration project identification, selection, design, evaluation, and permitting for CPW, and other state and federal personnel will be provided. Technical assistance includes review of stream restoration project designs for aquatic biologists and district wildlife managers (DWMs), site visits to proposed stream restoration locations, consultations with various agencies on stream restoration opportunities associated with highway and bridge improvement projects, project management of aquatic habitat treatment construction during highway bridge replacements or Fishing Is Fun (FIF) projects, consultations and technical support related to stream mitigation work for 404 permit violations, technical and physical assistance related to fish barrier design and construction, and teaching at various technical training sessions for CPW and other state and federal personnel.

INTRODUCTION

Job activities included: presentations to CPW (internal) and non-CPW (external) personnel, technical assistance to CPW area biologists and DWMs, technical assistance to non-CPW external government agencies and private consultants, technical assistance related the Upper Arkansas NRD (Natural Resource Damage) project, technical assistance related to design, construction, and monitoring of fish barriers, providing training to CPW personnel and acquiring additional technical expertise and professional job skills.

ACCOMPLISHMENTS

Presentations, CPW (internal)

Presentations to CPW personnel were delivered with the goal of increasing interactions and communication with Regional CPW staff (i.e. local Area meetings) and providing current research finding to the CPW Aquatic Section (Aquatic Biologists and Senior Aquatic Staff).

2011 Wildlife Commission Tour, Fort Collins, CO. “Stream Habitat Investigations, Matt Kondratieff, M.S., Aquatic Research Scientist.” December 7, 2011. Presented poster describing various research topics involving Stream Habitat Investigations to Wildlife Commissioners during a scheduled tour of CPW activities in the Northeast Region.

2012 Annual Aquatic Biologist Meeting (Section Meeting), Fort Collins, CO. “Fish habitat quality and fish movements associated with White Water Parks.” January 18, 2012.

2012 Northwest Biology Day Training (Regional Meeting), Grand Junction, CO. “Enhancing stream habitat for fisheries in Colorado.” February 22, 2012. Updated CPW Northwest regional staff (primarily law enforcement) on my current research topics, basic river mechanics and restoration principles, and results from monitoring fisheries response to habitat treatments.

2012 Southwest Biology Day Training (Regional Meeting), Gunnison, CO. “Hydrology of rivers and impacts of White Water Parks.” May 2, 2012. Updated CPW Southwest regional staff (primarily law enforcement) on my current research topics, basic river mechanics and restoration principles, and results from ongoing research on the influence of WWPs on fish passage and fish habitat quality.

Presentations, non-CPW (external)

Presentations to non-CPW personnel were delivered with the goal of communicating recent research findings to interested parties and educating students and professionals on river restoration techniques.

FW204, Introduction to Fisheries, Colorado State University, Fort Collins, CO. “Fish passage through kayak park structures: A case study.” December 5, 2012. Addressed undergraduate college students on fish habitat quality and fish passage problems associated with White Water Park structures.

U.S. Forest Service Region 2 Soils/Fisheries/Hydrology Forum, ARNFPNG Supervisor’s Office, Fort Collins, CO. “Fisheries response to habitat improvement.” March 21, 2012.

Wildlife Management Short Course 2012, Colorado State University, Fort Collins, CO. “Restoring Colorado Rivers” and “Introduction to Fisheries Science and Management” for Dr. Brett Johnson. March 27, 2012. Instructed 45 students of Dr. Decker’s 2012 Short Course on principles of fisheries science and management and river restoration principles and techniques.

Technical Assistance, CPW Staff (Senior Biologists, Area Biologists, Engineers, property technicians, DWMs, and AWMs)

We provided technical assistance to CPW internal staff as requested. Technical assistance included work related to evaluating fish passage at White Water Parks, culverts and other potential barriers, writing CPW position papers on a variety of fish habitat-related topics (e.g. White Water Parks), reviewing habitat restoration construction plans related to river restoration and trout habitat enhancement as part of the ACOE 404 permitting process, assisting with physical habitat surveys and equipment, assisting various property technicians on how to manage CPW properties with rivers in mind (e.g. appropriate locations for water gaps for cattle grazing), designing and reviewing fish barrier construction designs to protect native cutthroat trout populations, assisting Army Corps of Engineers (ACOE) staff and CPW water specialists to develop a new ACOE 404 permit (Regional General Permit 12) specifically for stream habitat improvement projects with fisheries-related goals for Colorado, providing aquatic biologists with cost estimates for specific habitat treatments to enhance sport fish populations in streams, providing technical expertise related to fish passage, providing technical expertise related proposal review and selection of stream habitat restoration firms, writing grants to generate funding for future habitat improvement projects, providing field consultation services to CPW staff related to potential stream habitat improvement projects and providing technical expertise related to river impacts from large-scale water development projects in Colorado (i.e. Windy Gap and Moffat Firming Project).

Technical Assistance, non-CPW External Government Agencies and Private Consultants

We provided technical assistance to non-CPW external government agencies and consultants as requested. Technical assistance was given specifically to the following private consultants: Ecometrics LLC. (Mark Beardsley), Ecological Resource Consultants (ERC), Stantec Engineering (river restoration team) and Biohabitats (Vince Sortman). Technical assistance included developing monitoring plans for evaluating stream habitat projects in South Park, CO, presenting fisheries concerns associated with WWP development, assisting with fish barrier designs and developing conceptual ideas for trout habitat improvement. Technical assistance to non-CPW external government agencies included the Army Corps of Engineers (ACOE), Colorado Department of Transportation (CDOT), Michigan Department of Natural Resources (DNR) and USFS. Assistance was specifically related to potential impacts of White Water Parks to fisheries, creation of a new ACOE 404 permit for stream restoration projects, developing plans to enhance trout habitat in Clear Creek in conjunction with an I-70 highway expansion project, assistance in writing and developing a white paper on the potential harm of WWP development on fisheries in Michigan and serving as a stream restoration expert assisting with development of restoration options for Armstrong Creek as part of a large-scale stream restoration project in the Steamboat Springs area.

Technical Assistance, Upper Arkansas NRD 11-mile project

We provided technical assistance to various agencies and organizations involved in the Upper Arkansas NRD project as requested. Technical assistance included: participation in Upper Arkansas Project trustees coordination meetings, LCOSI (Lake County Open Space Initiative) meetings and I-team meetings, technical and logistical planning with Brian Bledsoe (CSU Engineering Professor), Rod Van Velson (retired CDOW Aquatic Researcher), Tracy Kittell (CDOW design engineer) and Greg Policky (CDOW Aquatic Biologist). Review of publications, reports, and other relevant literature related to the Upper Arkansas River NRD project and presenting information regarding river restoration plans and research monitoring to interested publics and CPW staff as requested.

Technical Assistance: Design, Construction, and Monitoring of Fish Barriers

1) Assist area aquatic biologists to monitor fish barrier performance at existing sites.
No assistance was requested during this segment period.

2) Assist area aquatic biologists with fish barrier designs as needed

East Fork Parachute Creek: Continued to provide technical assistance to Lori Martin (CDOW Aquatic Biologist), Tracy Kittell (CDOW design engineer), Tom Fresques (BLM Fisheries Biologist) related to the design and implementation of a temporary fish barrier on East Fork Parachute Creek.

3) Provide technical assistance to biologists and Army Corps representatives involved in reviewing existing and proposed White Water Parks

Data from ongoing WWP studies and material from PowerPoint presentations on WWPs have been provided to CPW aquatic biologists engaged in WWP issues. Technical assistance was also provided to biologists from California, Tennessee, Idaho, Michigan and Minnesota who are actively engaged in WWP issues and fisheries.

Training to CPW Personnel

CDOW publication titled “Colorado Rivers” will be updated with new techniques and fish passage and barrier assessment materials. This is a work in progress. Kay Knudsen (CDOW librarian) is assisting to acquire necessary permissions to publish material from copyrighted materials in “Colorado Rivers” handbook so that it can be more widely (electronically) distributed to CDOW and non-CDOW personnel for training and educational purposes.

Continuing Education: Training to Gain Additional Technical Expertise and Professional Job Skills

Survey-grade GPS equipment: Received basic training on new survey grade GPS equipment from Trimble representative along with Tracy Kittell and other CPW design engineers. February 15-16.

Western Division AFS meeting 2012: Served as Fundraising Committee co-chairperson. Assisted in raising over $20,000.00 in fundraising dollars for 2012 Western Division AFS meeting, Jackson Hole, WY including the largest single donation of $2,500.00.

Physical Scientist Researcher position hiring process: Assisted with writing and contributing questions for written examination, requesting and gathering potential exam questions from subject matter experts, contacting and marketing to qualified candidates, and serving as a grader for written examination and oral interviews.

APPENDIX A

Wason and La Garita Ranch Monitoring Study

Project Goals and Background

In 2006, the Wason Ranch completed a large-scale habitat improvement project on approximately 3.8 miles of the Rio Grande River that flows through their property. The motivation for conducting this project was based on observations of anglers and ranch members that suggested a gradual degradation in the quality and quantity of fish in their privately-owned stretch of the Rio Grande River over time. While anglers caught some quality-sized fish (>14" or longer) in isolated pockets of the river, Wason members believed they were observing a gradual decline in overall fishing quality. They observed that the river had become wider and shallower over time due to stream bank erosion caused primarily by many years of historic cattle grazing, mining activities which caused excessive sediment contributions from upstream tributaries and historic logging/tie-hack drives. The banks had been broken down and stream side vegetation had been virtually eliminated due to cattle grazing. After consultation with a hydrologist specializing in trout stream restoration, members agreed to improve the river by implementing treatments related to the following goals: 1) elimination of bank erosion, 2) restoration of pre-impairment river depths, 3) restoration of the river channel and adjacent banks to pre-cattle grazing conditions and 4) revegetation of the banks. The Wason members believed that implementation of treatments related to meeting the above stated goals would create substantially more fish habitat that would increase total trout density and biomass and support greater abundance of quality-sized trout (14" and longer).

Colorado Parks and Wildlife is conducting an ongoing monitoring study of the fisheries response to fish habitat improvements on the Rio Grande River with cooperation from the Wason Ranch and La Garita Ranch near Creede, CO. The goal of this research effort is to determine how the fish habitat project has influenced the trout population by monitoring changes in biomass (kg/ha), density (fish ≥ 15 cm/ha), and numbers of quality –sized fish (fish ≥ 35 cm/ha). We determined that the Wason Ranch was an ideal location to conduct this study because: 1) we had seven years of fisheries data collected prior to any habitat improvement work (pre-data), 2) the scale of the habitat improvement reach is large (approximately 2 miles of intensively-treated river and 1.8 miles of lightly-treated river), 3) we have un-treated stream reaches up-and downstream of the improved river sections that can serve as spatial controls for the study (La Garita reach downstream is an ideal study control at 2.4 miles long), 4) although the river is publically accessible by raft for fishing (completely catch and release), the stream reaches are located on private stretches of the river which might remove some of the variability in fish estimates due to public fishing pressure from bank anglers, 5) there is evidence that brown trout numbers have stabilized post-whirling disease infection and 6) we have the ability to monitor these river sections over time with the future cooperation of the Wason and La Garita ranches.

We also believe the Wason Ranch and La Garita ranches are good locations for monitoring fish response because of the nature of the three reaches (Upper Wason, Lower Wason, and La Garita). All three reaches experienced the same historic land uses (grazing history and water quality issues from past mining). The Upper reach contains the most instream structures of the three reaches (J-hooks, vanes, cross vanes, off-channel developments) with many large, deep excavated pools for adult fish holding cover (Figure 1). The Lower Wason has fewer instream structures (J-hooks, cross vanes, excavated pools, etc.) than the Upper reach and consequently much fewer deep pools. Aside from containing fewer deep pools, the Lower reach is characterized overall by more randomly distributed boulders, wider channel dimensions and more streamside vegetation than the Upper reach (Figure 2). The La Garita reach has had the least amount of channel alterations/ improvements conducted on it. There are no instream structures in this reach such as J-hooks, cross vanes, W-weirs, or developed off-channel habitats. It has vegetated banks that are in similar condition to the Lower Wason reach, fewer large boulders than the Lower Wason and has more long areas of slow moving deep water (long runs). The channel width of the La Garita is probably closer to the Lower Wason than the Upper reach (Figure 3).

Figure 1. Upper Wason: Representative photo of the Upper Reach of the Wason Ranch. Notice the periodic large boulder-constructed cross-channel structures (cross vanes) used for grade control, creating deep pools, and narrowing the channels.

Figure 2. Lower Wason: Representative photo of the Lower Reach of the Wason Ranch. Notice the abundance of large protruding boulders, long riffles, coarse cobble substrate, lack of deep pools, lack of woody vegetation (alders and willows) and absence of large cross-channel structures.

Figure 3. Control Reach: Representative photo of the La Garita Reach downstream of the Upper and Lower Wason. Notice the over-wide channel with sparse woody vegetation (alders and willows), dominance of long, continuous riffles and run habitat, lack of deep pools and lack of large protruding boulders.

This report is a preliminary analysis of our finding up through our last fish sampling effort in October 2010. We are not making any conclusions yet related to how well the habitat improvements altered adult brown trout biomass (kg/ha for trout 6 inches or longer) or changed the number of adult and quality-sized fish (number of trout 14 inches or larger). Previous monitoring studies of habitat improvement projects suggest that it may require up to 5 years for trout populations to stabilize once construction is completed. This is why we are hoping to continue monitoring for at least an additional 2-4 years if possible. We are going to cover results pertaining primarily to brown trout and not rainbow trout since rainbow trout have been artificially planted in the river over time. As a consequence, rainbow trout population statistics will not serve as a good indicator of habitat improvement.

Results

<u>2010 sampling:</u> Water flows were low for 2010 (between 300 and 350 cubic feet per second) compared to previous years (greater than 350 cfs). Lower flows concentrated fish and consequently allowed us to increase our capture probabilities for adult fish. We continued using a second electrofishing raft this year doubling our sampling effort and allowing us to cover more of the river than with only one raft. As a result, our estimates have the tightest confidence intervals of any previous fish sampling (see Tables 1-5). The following are the results of this year's (Fall 2010) fish sampling.

<u>Pre-habitat versus post-habitat comparisons:</u> There are many factors that influence brown trout populations and thus trying to determine how the habitat improvements influenced the brown trout fishery is complex. Sampling results display a large variation in population and biomass estimates across years.

One approach is to average the trout fishery statistics (biomass, population size, densities) for all pre- and post- restoration years. Then we can compare these numbers to determine if there are any differences suggesting that a change in trout biomass or density has occurred from pre- and post-restoration conditions (see Table 1).

Using this approach, we can see that the Upper Wason reach appears to have experienced the largest increase in biomass of adult fish (35% increase, pre-compared to post-restoration) relative to the Lower reach (7 % increase, pre- compared to post-restoration). Also, we observe the largest increase in population size of adult brown trout (22% increase, pre-compared to post-restoration) for the Upper reach relative to the Lower reach (4% decline, pre- compared to post-restoration). One promising trend was the increase of quality-sized fish in both the Upper and Lower reaches with the number of quality-sized fish (14 inches and larger) nearly doubling (80% increase pre- compared to post-restoration) in the Upper reach and increasing by 62% (pre-compared to post-restoration) in the Lower reach. The increase in the number of quality-sized fish in the entire reach may be a result of regulation changes as well as from the improvement in habitat quality, especially for the Upper Wason reach.

<u>Population density estimates:</u> The Lower reach and the La Garita reach contained nearly identical densities of adult brown trout (6 inches and longer) with estimates of 284 adult brown trout/ha and 285 adult brown trout/ha respectively (Figure 4). The differences in adult brown trout density estimates between all sites are small (95% CIs overlap for all three sites). Therefore based on this year's sampling, we do not have sufficient evidence to conclude that improved reaches have higher densities of adult fish than un-improved sites. We plan to continue monitoring brown trout densities to determine if this will change over time.

<u>Biomass estimates:</u> Among the three reaches for 2010, the control reach (La Garita reach) had the highest biomass (83.1 kg/ha) for adult brown trout six-inches and longer followed by the Lower Wason (80.6 kg/ha) and the Upper Wason (65.4 kg/ha) respectively (Figure 5). This result is completely the reverse of last year's sampling (2009). However, the magnitude of the differences between reaches is not statistically significant (95% CIs overlap for all three sites). Therefore, we concluded that for this year's sampling, there is not sufficient evidence to

conclude that adult brown trout biomass differs among any of the three reaches. Additional years of fish sampling data from the La Garita will be very valuable as a means to compare against the Upper and Lower Wason in determining what influence the habitat improvements have on adult brown trout biomass.

The La Garita reach had the highest densities of quality-sized (14 inches and longer) brown trout. The La Garita reach held 29% (1.3 times) more quality-sized brown trout (> 14 inches) than the Lower Reach and 133% (or 2.3 times) more quality-sized brown trout than the Upper reach. The Lower reach has consistently had more quality-sized fish than the Upper across all years of sampling and again, this year was no exception. This difference has much to do with historic fishing regulations (8 trout/day in the Upper reach versus 2 trout/day, 14" maximum in the Lower reach from 1983-1986). We will need to investigate ways to separate any effects due to fishing regulations from effects due to habitat improvements. Interestingly, we did find evidence that the Upper Wason had statistically significantly FEWER quality-sized brown trout than either the La Garita or Lower reaches (95% CI for Upper Wason did NOT overlap with the other two sites, see Figure 7).

The largest brown trout captured was just under 20 inches long and the largest rainbow trout was approximately 20.5 inches long. The largest brown was captured from the Upper reach and the largest rainbow was captured from the Lower reach.

<u>Comparison across years:</u> We will review fish population statistics for all three reaches (Upper, Lower and La Garita). Population estimates have varied widely across years for all three reaches (Figure 6). Fluctuations in trout population statistics (i.e. population and biomass estimates) are caused by a number of factors including the following:

1) Magnitude and duration of flooding in high versus low snow-pack years.

Magnitude (highest peak flow) and duration (how long high flows persist) of high versus low snow-melt years influence brown trout fry survival. Brown trout year classes are highly correlated with water conditions during hatch-out and fry emergence. When brown trout emerge from the gravel under high run-off years, survival of brown trout fry is low and consequently a smaller number of adult fish (age 4 and older) will result from that year-class, 4 years later. Conversely, under low run-off years, brown trout fry survival is high and usually a higher number of adults will result from that particular year class 4 years later. This is important to understand when looking at the results of our data collection across years (see population estimates in Table 1: 1982-1983 compared with 1984-1986). The early '80s were some of the highest water years on record. Consequently, there are several year classes that were very small relative to age classes hatched in low water years. For instance, 1981 was a low water year with a peak flow of 2260 cfs compared to 1984 which had a peak flow of 4100 cfs (highest recorded mean daily peak flows). Refer to the life tables for the Upper and Lower Wason for examples of this effect (Table 6). The age 1 cohort for brown trout emerging in a low water year (1981) was 71 compared to only 9 in a high water year (1984) for the Lower Wason reach. Similarly, the density of the age 1 cohort for the Upper Wason reach that emerged in 1981 was 63 compared to 18 for 1984. These population effects are carried out over time and may lead to fluctuations in trout densities (number of fish per area) and biomass (weight of fish per area).

2) Electrofishing efficiency in high versus low water conditions.

Under low flow conditions, more fish are captured by electrofishing which increases the capture probability of individual fish leading to more accurate fish population estimates. Conversely, higher flows make fish sampling more difficult since individual fish have lower capture probabilities and thus leads to less accurate fish population estimates.

3) Changes in fishing regulations.

In 1983, regulations for the Lower Wason (flywater) reach changed from a 2 trout/day, 14 inch minimum size limit to 2 trout/day, 14 inch maximum size limit. This change stopped the harvest of 14-inch and longer brown trout and protected larger, quality-sized fish (14 inches and longer) resulting in more large fish, particularly in the Lower Wason. The current regulations in place for anglers fishing on the Wason and La Garita ranch are catch-and-release only for the entire reach. We see that over time, there has been a steady trend of more quality-sized fish in the entire Wason Ranch reach, with the exception of this year (see Figure 7). We believe this trend can be explained by this regulation change in 1983 and the catch-and-release policy currently enforced by both the Wason and La Garita Ranches. Another example of how this change in regulation led to population changes is reflected in the life tables (see Table 6: Lower Wason life tables, 1982-1986 compared with 2008-2009 data). We see in 1982 that there are only 4 age-classes represented in the brown trout population for both upper and lower Wason reaches. In 2008, 2009 and 2010, we see that 6 to 8 age-classes are present. This increase in survival of older age classes is because of the change in regulation that protected these larger-sized fish, allowing brown trout to live longer and potentially grow larger.

4) Channel width computations.

We used a constant channel width value of 100 feet to make comparisons across the three reaches across all years. Channel width is used along with the reach length to determine the area sampled (hectares). Using a 100 foot width across all reaches for the pre-habitat improvement years is probably correct. However, one of the goals of the restoration work was to create a deeper, narrower channel in the Upper Reach in particular. We would like to survey the wetted width at an appropriate flow (Fall flows that are representative of when we usually sample) to determine if there is variation in channel widths between reaches. This is important because biomass and densities are very sensitive to this habitat variable (i.e. we will under-estimate biomass for the Upper Reach if we use a width of 100 feet when we should be using 75 feet instead). This has implications for how much improvement (or not) that we see in the trout fishery post-restoration.

In spite of these various factors that might influence trout population statistics, we were able to make the following observations about brown trout populations across all years of sampling.

The Lower Wason reach consistently has higher adult (six inches and larger) brown trout biomass (kg/ha) than the Upper Wason across all eight years of sampling with the exception of 2008 fish sampling (Figure 5). The Lower Wason has an average of 18.7 kg/ha higher adult brown trout biomass than the Upper Wason Reach. Differences between the Lower and Upper reach ranged from no difference (1983 and 2009) to over 53 kg/ha greater adult brown trout biomass on the Lower Reach than the Upper (1984). We have not collected enough years of fish sampling data from the La Garita reach to make any accurate comparisons. The Lower Wason had higher adult brown trout biomass than the La Garita in 2009, but not in 2010. Also, differences in adult brown trout biomass between the La Garita and Lower Wason were not statistically significant using an alpha of 0.05.

Across all eight years of sampling, the Lower Wason reach has always had a larger population density of quality-sized (14 inches and larger) brown trout than the Upper Wason (Figure 7). The Lower Wason has an average of 20 quality-sized brown trout/ha more than the Upper Wason Reach. Differences between the Lower and Upper reach ranged from 6 quality-sized brown trout/ha in 1985 to over 51 quality-sized brown trout/ha more quality-sized brown trout on the Lower Reach than the Upper (1984). However, it is important to note that these differences in the numbers of quality-size brown trout between the Upper and Lower Wason reaches during the sampling period from 1982 through 1986 was a result of differences in fishing regulations. The Upper section was under an 8-trout/day bag limit with bait angling allowed, compared to a fly-only terminal tackle restriction and a 14-inch maximum size limit in effect on the lower reach from 1983 through 1986. We have not collected enough years of fish sampling data from the La Garita reach to make any accurate comparisons. The Lower Wason had higher quality-sized brown trout densities than the La Garita in 2009, but not in 2010. Also, differences in adult brown trout biomass between the La Garita and Lower Wason were not statistically significant using an alpha of 0.05.

Consequently, the percentage of quality-sized fish out of the total population of adult brown trout has steadily increased from less than 10% of the population consisting of quality-sized-or- larger fish in 1982 for both reaches to approximately 33% quality-sized-or- larger fish for the Lower Wason and 20% quality-sized-or- larger fish for the Upper reach for 2008 and 2009 (see Figure 8).

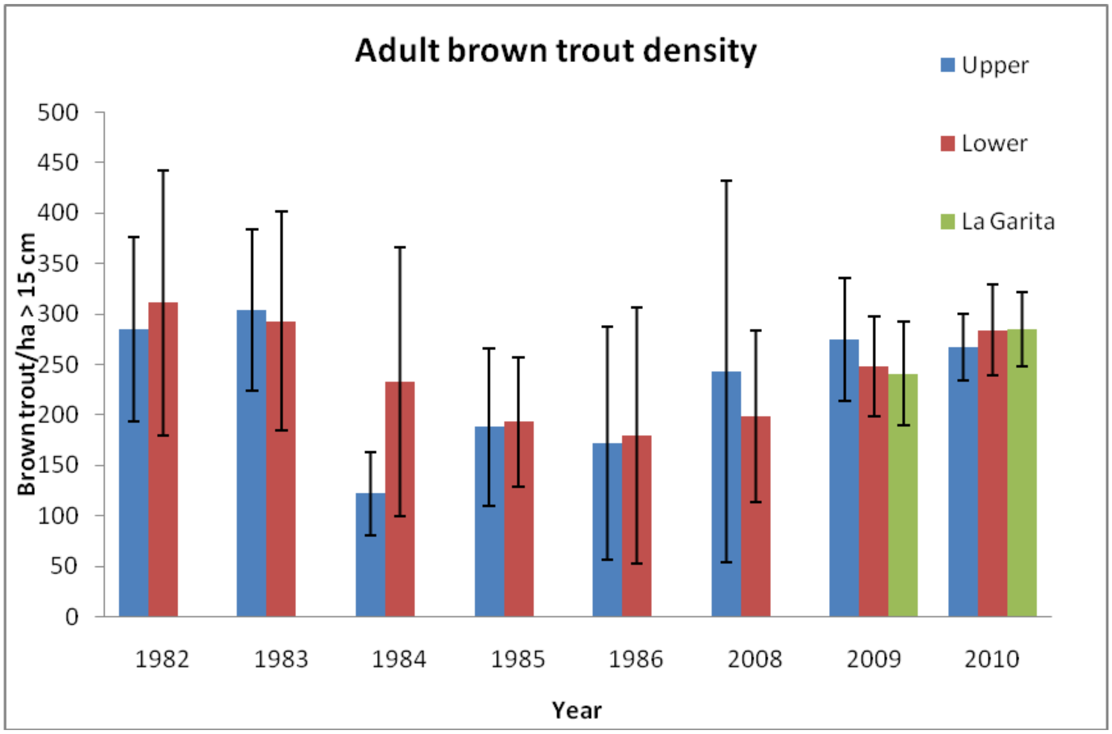

Figure 4. Population density estimates of adult (>15 cm) and longer brown trout in the Upper Wason, Lower Wason and La Garita reaches. Pre-restoration sampling estimates include years: 1982, 1983, 1984, 1985 and 1986. Post-restoration sampling estimates include years: 2008, 2009 and 2010. Black vertical bars represent 95% CI for the estimate.

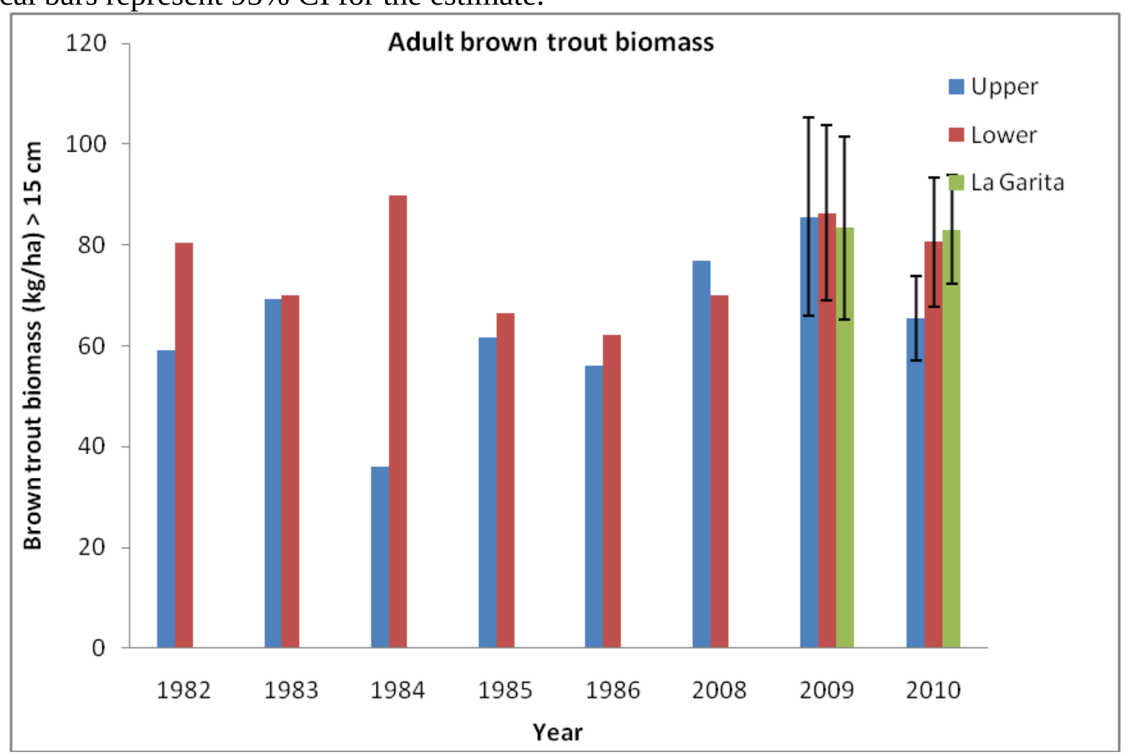

Figure 5. Biomass (kg/ha) of adult (6 inch and longer) brown trout in the Upper Wason, Lower Wason and La Garita reaches. Pre-restoration sampling estimates include years: 1982, 1983, 1984, 1985 and 1986. Post-restoration sampling estimates include years: 2008, 2009 and 2010. Black vertical bars represent 95% CI for the estimate.

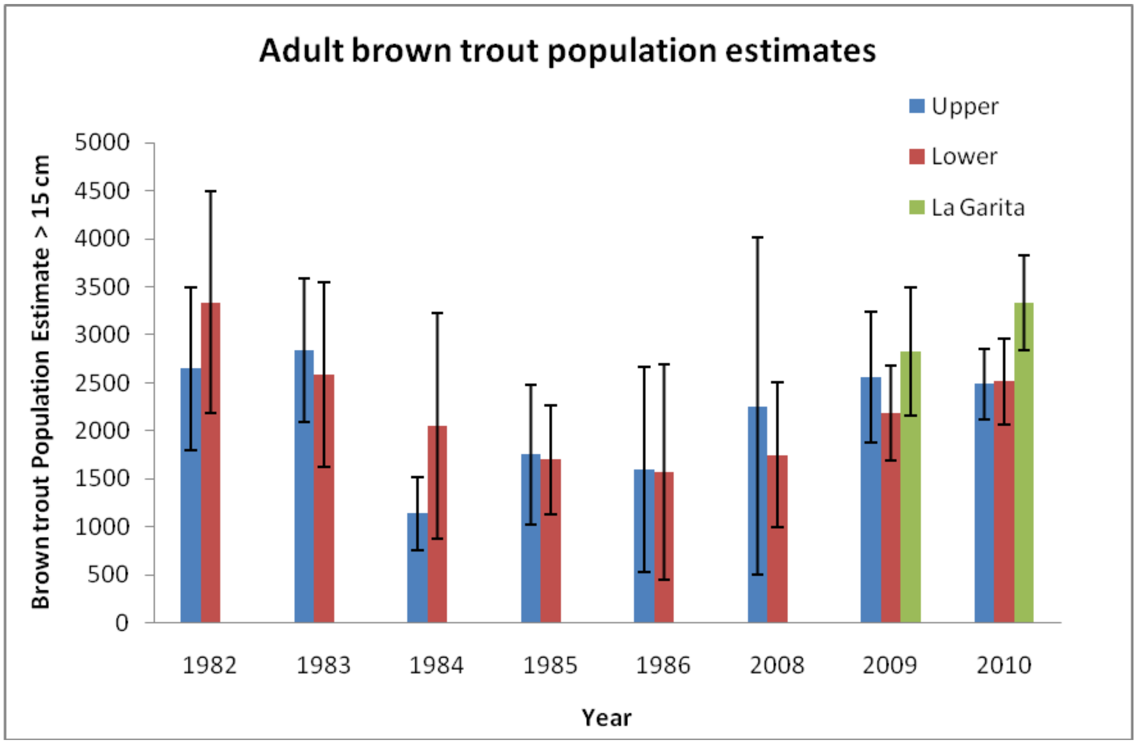

Figure 6. Population estimates of adult (>15 cm) and longer brown trout in the Upper Wason, Lower Wason and La Garita reaches. Pre-restoration sampling estimates include years: 1982, 1983, 1984, 1985 and 1986. Post-restoration sampling estimates include years: 2008, 2009 and 2010. Black vertical bars represent 95% CI for the estimate.

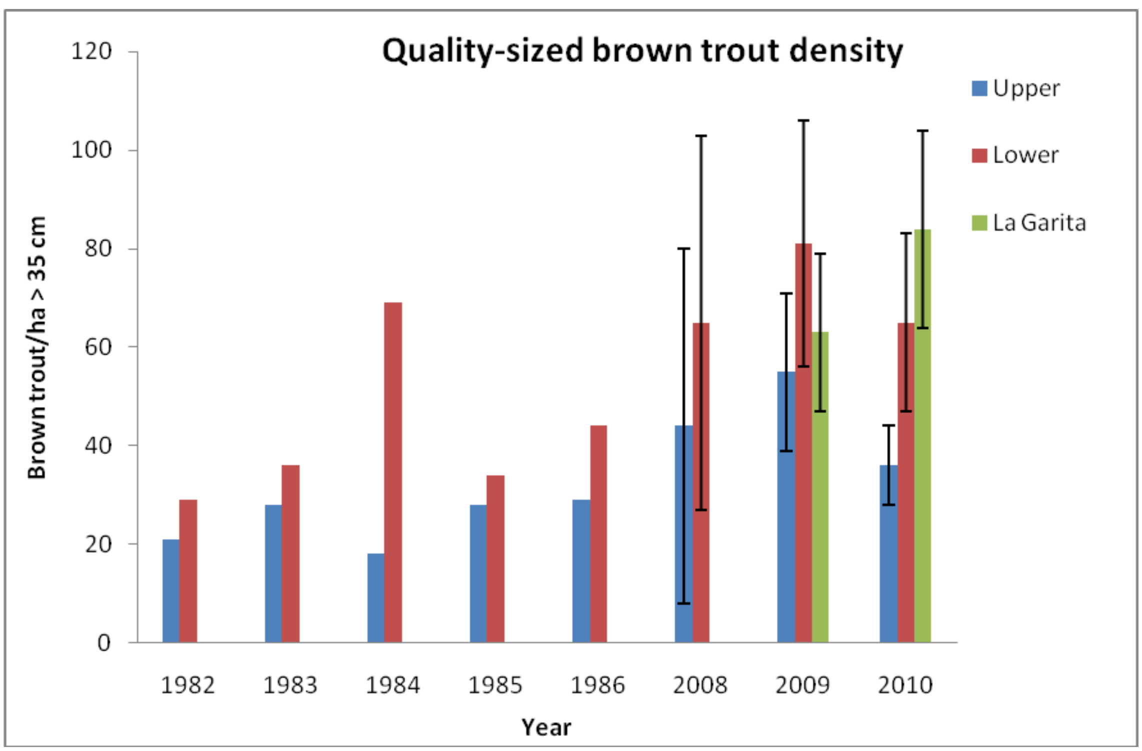

Figure 7. Density (trout/ha) of quality-sized (14 inch and longer) brown trout in the Upper Wason, Lower Wason and La Garita reaches. Black vertical bars represent 95% CI for the estimate.

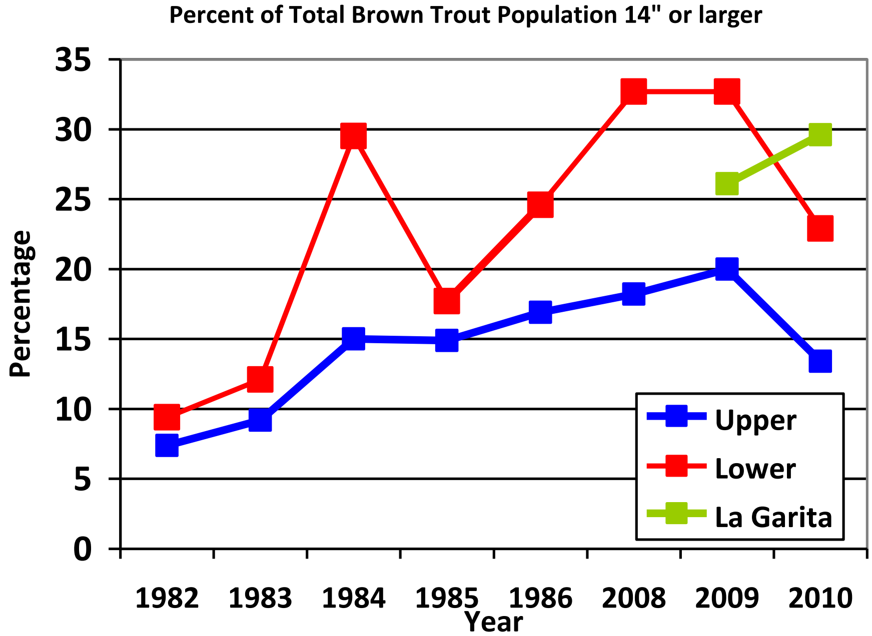

Figure 8. Percent of total trout population consisting of quality-sized (14" or longer) brown trout in Upper and Lower Wason reaches.

Conclusions

Future research directions: In addition to our annual Fall sampling, we are considering adding the following research components to the project to help us refine this study: 1) we would like permission to survey the river channel under a range of conditions that will help us improve our abilities to monitor fish habitat improvements and monitor function of individual channel structures (such as J-hooks and cross vanes), 2) we are interested in conducting a telemetry study of adult brown trout and tracking their movements, particularly during the winter, to determine how where brown trout over-winter. We suspect that the addition of deeply excavated pools especially in the Upper Reach may provide critical habitat for adult fish to over-winter when flows are limiting, temperatures are coldest, and ice reduces connectivity of river micro-habitats (i.e. ability of fish to move longer distances up- or downstream). Lastly, 3) we are interested in monitoring fish movement in and out of off-channel habitats. We are especially interested in tracking fish movements between off-channel ponds on the Lower Wason and the main-stem Rio Grande River.

We have reported preliminary results of fish sampling on the Wason and La Garita ranches. Without further fish sampling and monitoring, we still cannot conclude whether or not habitat improvements influence brown trout populations. Therefore, we hope to continue to work with the Wason and La Garita Ranches in order to continue collecting data on trout fisheries on the Rio Grande River. We thank the Wason and La Garita Ranches for continuing to allow us to conduct this research on their property and their generousity in providing both direct assistance (volunteers, coffee and donuts) and permission to allow us to work in the river. We also thank Barry Nehring for his assistance with coordinating/planning fish sampling efforts and for serving as a reviewer of this report. Our hope is that results from this study will provide guidance on future restoration work and assist ranch managers in understanding what types of habitat improvements are maximizing benefits to the trout fisheries.

Table 1. Summary of brown trout population estimates (N), biomass estimates (Kg/ha) and numbers of "quality" size (n≥35 cm or 14 inches) and density of "quality" size (n≥35 cm/ha) statistics for the Wason Ranch and La Garita reach of the Rio Grande, Fall 1982-1986, 1992, 1999, 2008, 2009 and 2010.

Year	**Upper Reach - 3.06 km**				**Lower Reach – 2.9 km**				**La Garita Reach – 3.84 km**			
	N	**Kg/ha**	**n≥35 cm**	**n≥35 cm/ha**	**N**	**Kg/ha**	**n≥35 cm**	**n≥35 cm/ha**	**N**	**Kg/ha**	**n≥35 cm**	**n≥35 cm/ha**
	Pre-Habitat Improvement Treatment Period											
1982	2,648	59.2	195	21	3,336	80.4	312	29	N/A	N/A	N/A	N/A
1983	2,835	69.3	262	28	2,581	70.1	312	36	N/A	N/A	N/A	N/A
1984	1,136	36.1	170	18	2,055	89.9	607	69	N/A	N/A	N/A	N/A
1985	1,751	61.7	260	28	1,700	66.4	300	34	N/A	N/A	N/A	N/A
1986	1,602	56.0	270	29	1,573	62.1	387	44	N/A	N/A	N/A	N/A
Average	**1,994**	**56.5**	**231**	**24.8**	**2,249**	**73.8**	**384**	**42**	**-**	**-**	**-**	**-**
	Post - Habitat Improvement Treatment Period											
2008	2,256	77.0	410	44	1,749	70.1	572	65	N/A	N/A	N/A	N/A
2009	2,555	85.6	510	55	2,190	86.4	716	81	2,823	83.4	737	63
2010	2,487	65.4	332	36	2,512	80.6	575	65	3,332	83.1	985	84
Average	**2,433**	**76.0**	**417**	**45**	**2,150**	**79.0**	**621**	**70**	**3,078**	**83.3**	**861**	**74**
% Change	**+22.0**	**+34.5**	**+80.5**	**+81.5**	**-4.4**	**+7.1**	**+61.7**	**+66.7**	**-**	**-**	**-**	**-**

Table 2. Trout population statistics for the upper 3.06 km reach of the Rio Grande on the Wason Ranch, Fall 1982-1986, 2008, 2009 and 2010.

Year	N ≥ 15 cm	95% C.I. ≥ 15 cm	Fish/ha ≥ 15 cm	Kg/ha ≥ 15 cm	Fish/ha ≥ 35 cm
Brown Trout					
1982	2,648	±850	285	59.2	21
1983	2,835	±746	304	69.3	28
1984	1,136	±385	122	36.1	18
1985	1,751	±728	188	61.7	28
1986	1,602	±1,069	172	56.0	29
2008	2,256	±1,761	243	77.0	44
2009	2,555	±680	275	85.6	55
2010	**2,487**	**±368**	**267**	**65.4**	**36**
Rainbow Trout					
1982	325	±432	35	5.7	1
1983	247	±134	27	5.6	3
1984	83	±63	9	2.4	2
1985	126	±162	14	3.6	3
1986	94	±52	10	2.4	1
2008**a**	567	±346	61	37.1	51
2009	269	±137	29	17.9	25
2010	**143**	**±78**	**15**	**7.8**	**10**
Total Trout					
1982	3,082	±948	331	64.9	22
1983	3,096	±745	332	74.9	31
1984	1,236	±391	133	38.5	20
1985	1,948	±791	209	65.3	31
1986	1,377	±682	148	58.5	24
2008	2,660	±1,396	286	114.1	102
2009	2,765	±654	297	103.5	80
2010	**2,640**	**±383**	**284**	**73.2**	**46**

a: The Wason Ranch purchased and stocked approximately 600 pounds of rainbow trout in the river in 2005 and 2006, 1,950 pounds in 2007, and 1,000 pounds in 2008. These fish were 16 to 18 inches in length.

Table 3. Trout population statistics for the lower 2.90 km reach of the Rio Grande on the Wason Ranch, Fall 1982-1986, 2008, 2009 and 2010.

Year	N ≥ 15 cm	95% C.I. ≥ 15 cm	Fish/ha ≥ 15 cm	Kg/ha ≥ 15 cm	Fish/ha ≥ 35 cm
Brown Trout					
1982	3,336	±1,157	311	80.4	29
1983	2,581	±964	293	70.1	36
1984	2,055	±1,176	233	89.9	69
1985	1,700	±568	193	66.4	34
1986	1,573	±1,122	179	62.1	44
2008	1,749	±750	198	70.1	65
2009	2,190	±494	248	86.4	81
2010	**2,512**	**±453**	**284**	**80.6**	**65**
Rainbow Trout					
1982	39	±52	4	1.5	0
1983	80	±149	9	1.2	1
1984	171	±103	10	1.9	0
1985	15	±7	2	0.4	1
1986	59	±41	7	2.0	2
2008**a**	92	±59	10	5.8	7
2009	91	±59	10	5.8	7
2010	**87**	**±57**	**10**	**4.8**	**3**
Total Trout					
1982	3,021	±1,245	343	81.9	29
1983	2,745	±1,027	311	71.3	37
1984	1,994	±1,091	227	90.2	69
1985	1,609	±501	183	66.8	35
1986	1,425	±842	162	64.1	41
2008	1,750	±664	198	75.9	67
2009	2,272	±488	257	92.2	88
2010	**2,629**	**±470**	**297**	**85.5**	**69**

a: The Wason Ranch purchased and stocked approximately 600 pounds of rainbow trout in the river in 2005 and 2006, 1,950 pounds in 2007, and 1,000 pounds in 2008. These fish were 16 to 18 inches in length.

Table 4. Trout population statistics for the entire 5.96 km reach of the Rio Grande on the Wason Ranch, Fall 1982-1986, 2008, 2009 and 2010.

Year	N ≥ 15 cm	95% C.I. ≥ 15 cm	Fish/ha ≥ 15 cm	Kg/ha ≥ 15 cm	Fish/ha ≥ 35 cm
Brown Trout - Pre-Habitat Treatment					
1982	5,286	±1,353	292	69.5	24
1983	5,325	±1,148	294	68.3	31
1984	2,776	±821	153	41.0	33
1985	3,419	±892	188	50.2	41
1986	3,597	±1,891	198	52.5	41
1992	3,497	±889	192	64.4	64
1999	5,096	±1,637	280	80.3	82
Brown trout - Post-Habitat Treatment					
2008	3,768	±1,454	207	70.7	62
2009	4,717	±814	259	85.7	69
2010	**4,974**	**±569**	**273**	**72.8**	**49**
Rainbow Trout - Pre-Habitat Treatment					
1982	620	±513	34	3.0	1
1983	336	±187	19	2.8	2
1984	103	±67	6	1.6	1
1985	92	±57	5	1.3	1
1986	159	±81	9	2.3	2
1992	620	±233	34	14.4	19
1999	69	±41	4	1.3	2
Rainbow Trout -Post-Habitat Treatment					
2008**a**	672 **a**	±340	37	22.0	27
2009	367	±151	20	10.8	16
2010	**246**	**±148**	**14**	**6.9**	**6**
Total Trout - Pre-Habitat Treatment					
1982	6,128	±1,517	339	72.5	25
1983	5,656	±1,148	312	71.1	33
1984	2,831	±786	156	42.6	34
1985	3,467	±859	190	51.5	42
1986	2,878	±1,119	158	55.0	32
1992	4,007	±848	220	78.3	84
1999	4,878	±1,456	268	81.6	80
Total Trout - Post-Habitat Treatment					
2008	4,207	±1,297	231	92.7	86
2009	5,022	±801	276	97.8	85
2010	**5,230**	**±588**	**287**	**79.4**	**56**

a: The Wason Ranch purchased and stocked approximately 600 pounds of rainbow trout in the river in 2005 and 2006, 1,950 pounds in 2007, and 1,000 pounds in 2008. These fish were 16 to 18 inches in length.

Table 5. Trout population statistics for the 3.84 km reach of the Rio Grande on the La Garita Ranch, Fall 2009 and 2010.

Year	N ≥ 15 cm	95% C.I. ≥ 15 cm	Fish/ha ≥ 15 cm	Kg/ha ≥ 15 cm	Fish/ha ≥ 35 cm
Brown Trout					
2009	2,823	±669	241	83.4	63
2010	**3,332**	**±492**	**285**	**83.1**	**84**
Rainbow Trout					
2009	67	±52	6	3.2	4
2010	**44**	**±40**	**4**	**1.4**	**1**
Total Trout					
2009	2,916	±680	249	86.7	68
2010	**3,391**	**±500**	**290**	**84.5**	**86**

Table 6. Life Tables-Rio Grande River (brown trout/ha) for Fall 1982-1986, 2008, 2009 and 2010.

Wason Ranch-Upper-standard regulations-8 trout/day 1982-1986

Sample Period		**Year Class**										
Month	**Year**	**1985**	**1984**	**1983**	**1982**	**1981**	**1980**	**1979**	**1978**	**1977**	**1976**	**1975**
August	**1982**					**63**	**99**	**136**	**13**	**0**	**0**	**0**
September	**1983**				**61**	**130**	**63**	**41**	**9**	**0**	**0**	**0**
October	**1984**			**27**	**27**	**30**	**32**	**5**	**1**	**0**	**0**	
October	**1985**		**18**	**94**	**45**	**25**	**5**	**1**	**0**	**0**		
October	**1986**	**29**	**48**	**67**	**11**	**10**	**5**	**0**	**0**			

Age 1 fish

Age 4 fish

Wason Ranch-Upper-catch-and-release only

Sample Period		**Year Class**									
Month	**Year**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
October	**2008**			**11**	**28**	**105**	**56**	**20**	**12**	**0**	**0**
October	**2009**		**13**	**64**	**77**	**63**	**51**	**6**	**4**	**1**	**0**
October	**2010**	**49**	**79**	**60**	**47**	**30**	**3**	**3**	**0**		

Age 1 fish

Age 4 fish

Wason Ranch-Lower-flywater- 2 trout/day; 14 inch min (1982). 2 trout/day; 14 inch max (1983-1986)

Sample Period		**Year Class**										
Month	**Year**	**1985**	**1984**	**1983**	**1982**	**1981**	**1980**	**1979**	**1978**	**1977**	**1976**	**1975**
August	**1982**					**71**	**98**	**190**	**19**	**0**	**0**	**0**
September	**1983**				**61**	**123**	**58**	**38**	**13**	**0**	**0**	**0**
October	**1984**			**43**	**30**	**50**	**89**	**14**	**6**	**0**	**0**	
October	**1985**		**9**	**67**	**96**	**16**	**5**	**1**	**0**	**0**		
October	**1986**	**33**	**45**	**63**	**13**	**13**	**11**	**0**	**0**			

Age 1 fish

Age 4 fish

Wason Ranch-Lower-catch-and-release only

Sample Period		Year Class									
Month	**Year**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
October	**2008**			**14**	**13**	**79**	**48**	**20**	**11**	**0**	**0**
October	**2009**		**7**	**48**	**66**	**62**	**50**	**9**	**6**	**1**	**0**
October	**2010**	**50**	**76**	**55**	**65**	**37**	**5**	**6**	**0**		

Age 1 fish

Age 4 fish

La Garita-catch-and-release only

Sample Period		Year Class									
Month	**Year**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
October	**2008**			**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
October	**2009**		**10**	**46**	**54**	**67**	**60**	**7**	**2**	**0**	**0**
October	**2010**	**43**	**71**	**61**	**65**	**44**	**4**	**5**	**0**	**0**	

Age 1 fish

Age 4 fish

List of symbols and terminology

Adult fish	=	Arbitrary category assigned to a fish that has a total length of 6 inches or longer.
Biomass	=	Mass or weight of fish per area, (for example, kilograms brown trout per hectare).
Cfs	=	Unit volumetric flow rate, which is equivalent to the volume of 1 cubic foot flowing every second.
Cm	=	Symbol of length which is equal to one hundredth of a meter (1 inch = 2.54 cm).
Density	=	Measurement of population per unit area or unit volume (for example, number of brown trout per hectare).
"≥" "≤" ">" or "<"	=	Symbols for "greater than or equal to," "less than or equal to," "greater than" or "less than" respectively.
Ha	=	Hectare (see definition of "hectare").
Hectare	=	A hectare (symbol ha) is a unit of area equal to 10,000 square meters (107,639 sq ft) and is commonly used for measuring surface area.
"	=	Symbol for inches, such as a 14" long fish.
Kg	=	Kilogram which is a unit of mass that weighs 1000 grams or 2.2 pounds (lbs).
Life table	=	Life tables are generated by combining trout population estimates and trout age/growth data (from scales) to show relative abundances of various trout age-classes.
Mile	=	Unit of length that is equivalent to 5,280 feet
N	=	Symbol for population abundance (estimated).
Quality-sized fish	=	Arbitrary category assigned to a fish that has a total length of 14 inches or longer.
Total length	=	Length of a fish measured from a fish's snout to the end of the compressed caudal fin.
95% C.I.		A 95% confidence interval for a population parameter (such as population abundance, N) is an indicator of the uncertainty of an estimate. The larger the interval, the less precise or reliable the estimate. If a sampling procedure used to generate a specific estimate (i.e. population abundance, N) was repeated 100 times using the identical protocal, crew, and equipment, on average, 95 times out of 100 the true parameter would fall within the 95% confidence interval generated for the particular estimate. In other words, we are 95% confident that the true population parameter is included with the 95% confidence interval for that estimate.